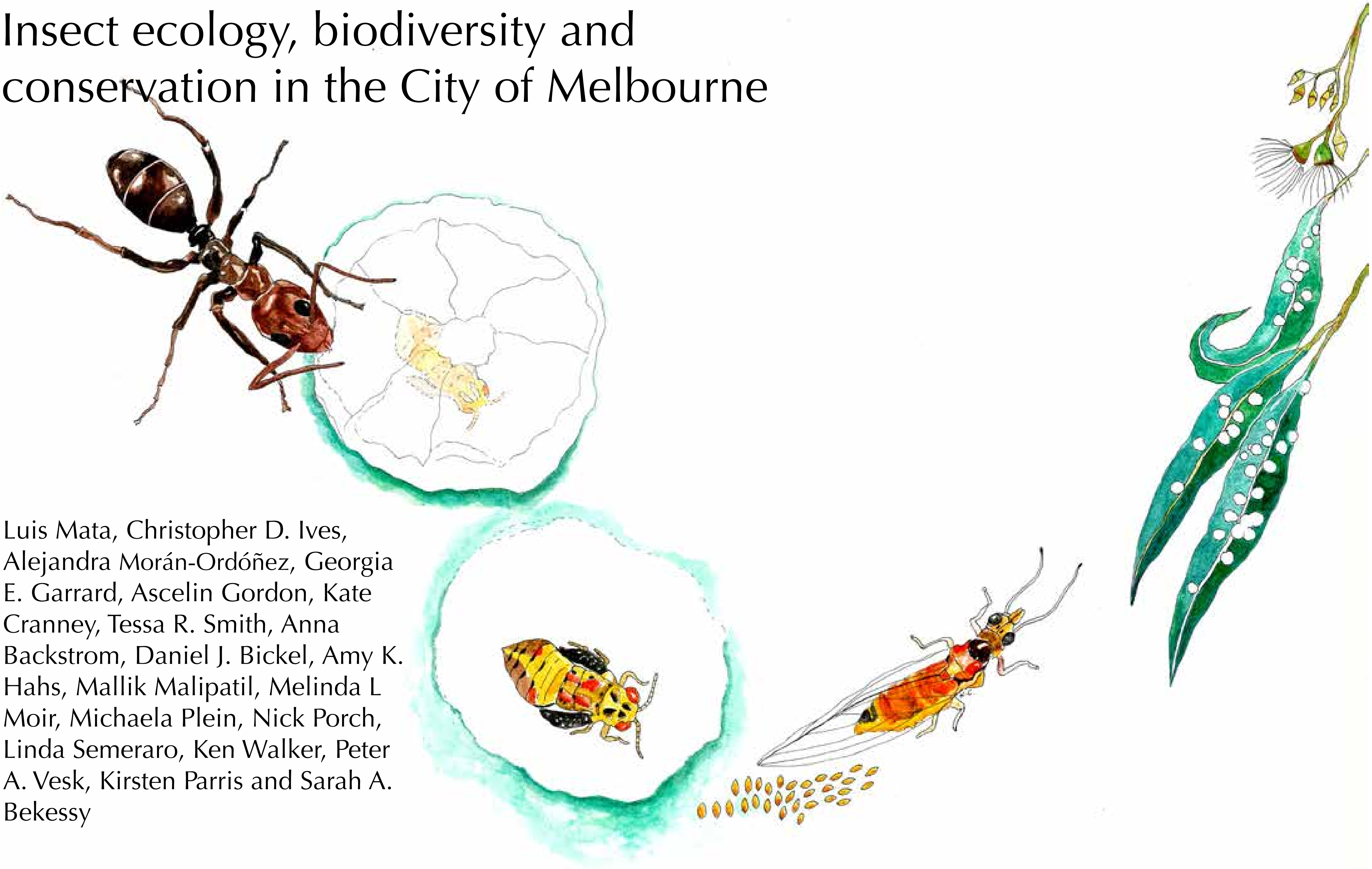
The Little Things that Run the City

Insect ecology, biodiversity and conservation in the City of Melbourne



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Report prepared for the City of Melbourne, August 2016

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Cover artwork by Kate Cranney **‘Ant and lerps’** (Ink and paper on paper, 2016)

Beetle stacked macro-photographs by Nick Porch.

Dryinidid wasp stacked macro-photograph by Ken Walker.

All other photographs by Luis Mata unless otherwise stated.

The version of the report was finished in Melbourne (Victoria, Australia) the 15th of September 2016.

Please cite as:

The Little Things that Run the City – Insect ecology, biodiversity and conservation in the City of Melbourne (2016) Mata L, Ives CD, Morán-Ordóñez A, Garrard GE, Gordon A, Cranney K, Smith TR, Backstrom A, Bickel DJ, Hahs AK, Malipatil M, Moir ML, Plein M, Porch N, Semeraro L, Walker K, Vesk PA, Parris KM, Bekessy SA. Report prepared for the City of Melbourne.

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Acknowledgements

We are very grateful to the City of Melbourne for co-funding this project. We'd especially like to thank Ian Shears, Yvonne Lynch, Amy Rogers and Lingna Zhang from the Urban Sustainability Branch for their ongoing support and enthusiasm.

We would also like to acknowledge the support of funding from RMIT University's Strategic Projects in Urban Research (SPUR) Fund, the National Environmental Science Programme - Clean Air and Urban Landscapes Hub (NESP - CAUL) and the Australian Research Council - Centre of Excellence for Environmental Decisions (CEED).

Thanks to Esti Palma, Michelle Freeman, Dave Duncan, Xavier Francoeur and Laura Stark for their invaluable help with fieldwork, insect sorting and data analysis.

We are grateful to Dayanthi Nugegoda, Jeff Shimeta, David Heathcote and Shannon Fernandes from RMIT University's Applied Sciences Lab for providing the laboratory workspace and equipment necessary to undertake the insect sorting and identification phase of this project.

We are also grateful to Alan Andersen and Rolf Oberprieler for generously providing help with ant and weevil species identifications and advice on species biology and ecology. Also thanks to Steve Sinclair, who identified the black-anther flax-lily *Dianella admixta* in which we observed the blue-banded bee in Royal Park, and Tony Daley and Martin Lagerwey, who contributed species identifications through the BowerBird platform.

Contents

1 The Little Things that Run the City project

How did The Little Things that Run the City get its name?

The Little Things that Run the City has been inspired by Edward O. Wilson's famous quote:

> *"…let me say a word on behalf of these little things that run the world"*

The quote was part of an address given by Wilson on occasion of the opening of the invertebrate exhibit of the National Zoological Park (Washington D.C., USA). It later appeared in writing format in the first volume of the journal *Conservation Biology* (Wilson 1997). The key objective of Wilson's address was to stress the urgent need to recognise the importance of insects and other invertebrates for humanity. Almost 30 years ago he was keen to see that efforts aimed at the conservation of biodiversity were beginning to also include non-vertebrate animals. In his words: *"A hundred years ago few people thought of saving any kind of animal or plant. The circle of concern has expanded steadily since, and it is just now beginning to encompass the invertebrates. For reasons that have to do with almost every facet of human welfare, we should welcome this new development."*

In this research collaboration with the City of Melbourne we aim to expand the circle further to also encompass the conservation of insects and other invertebrates in urban environments. We are inspired to 'say a word on behalf of the little things that run the city'.

Why are insects so important?

With more than one million described extant species, insects (Figures 1.1 and 1.2) are the most diversified animal taxa on planet Earth (Stork 2007, Adler and Foottit 2009). Not unexpectedly, insect species account for as much as 66% of all known animals (Zhang 2011). The core importance of insects to humanity, however, does not reside alone in their diversity, but in the roles that they play in structuring networks of ecological interactions in almost all terrestrial and freshwater ecosystems throughout the biosphere (Waldbauer 2003, Bascompte and Jordano 2007, Ings et al. 2009, Scudder 2009). Moreover, through their capacity to pollinate flowers, transform biomass, regulate pest populations, recycle nutrients, disperse seeds, and provide food, insects are arguably planet Earth's most important contributors of biodiversity-delivered ecosystem services (Kremen and Chaplin-Kremer 2007, Straub et al. 2008, Prather et al. 2013).

Why should we strive to conserve insects in urban environments?

Insects are a critical component of urban biodiversity (Sattler et al. 2011, Mata 2013, Threlfall et al. 2015). The ecological functions they perform within and beyond the boundaries of cities translate into a plethora of ecosystem services (Losey and Vaughan 2006, Kremen and Chaplin-Kremer 2007, Straub et al. 2008, Prather et al. 2013, Benett and Lovell 2014, Baldock et al. 2015) and disservices (Dunn 2010, Rust and Su 2012) that are delivered constantly to city-dwellers.

Presently, however, the paucity of data on the diversity and ecological roles of insects in urban ecosystems is hindering progress in ecology and conservation science at the national, continental and planetary scales (Stork 2007, Cranston 2010, New and Yen 2012, New and Samways 2014). There is therefore a great need for research into the insect biodiversity of urban environments for both scientific advancement and urban sustainability practice.

Is the City of Melbourne interested in conserving insect biodiversity?

The City of Melbourne's (Figure 1.3) commitment to sustainability and biological conservation is reflected in its Urban Forest and Open Space strategies (City of Melbourne 2012a, 2012b) and the goals set in its latest four-year Council Plan (City of Melbourne 2013). The council's interest and concern for the insect biodiversity occurring within its boundaries is distinctly reflected in its soon to be released 'Urban ecology and biodiversity strategy'. Insect biodiversity was also a central theme and focus of its two most recent 'BioBlitz' events (Ives et al. 2015), as well as of the recent 'Target species for rewilding, monitoring and public engagement in the City of Melbourne' workshop (Mata et al.

Figure 1.1 (Opposite page) Diversity of insect life I.









2016). Arguably however, the most compelling evidence of the municipality's commitment to the understanding of insects and their associated benefits is the support of the present study 'The Little Things that Run the City'.

Was the research in The Little Things that Run the City a purely academic (or consultancy) endeavor?

No On the contrary, the research was developed following the collaborative partnership model of science-government partnerships (Ives and Lynch 2014). Not unlike mutualistic plant-insect ecological interactions in nature, this approach advocates for government professionals and academic researchers to work in close association to generate mutually beneficial outcomes. To guarantee that both theoretically interesting and practically important questions are identified, Ives and Lynch (2014) propose that the key research questions ought to be developed collaboratively between researchers and practitioners. The project was further envisioned as an outreach tool, and aimed to rise awareness of insects and ecosystem processes in the general public.

What were the project's key research questions?

We applied the approach described above to formulate the following research questions:

1. Which are the key insect groups living in the City of Melbourne?

2. Which are the most frequently occurring insect species in the City of Melbourne?

3. How is the insect biodiversity of the City of Melbourne distributed amongst its public green spaces?

4. How is the insect biodiversity of the City of Melbourne distributed amongst the different habitat types in these green spaces?

5. What are the most frequent ecological interactions between plants and insects in the City of Melbourne?

6. What are the ecological functions performed by insects in the City of Melbourne?

7. What are the ecosystem services delivered by the City of Melbourne's insect biodiversity that benefit people?

Figure 1.2 (Opposite page) Diversity of insect life II.









How will the project's findings inform the City of Melbourne's biodiversity management guidelines and policy?

The Little Things that Run the City project will illustrate the importance of insect biodiversity conservation to the City of Melbourne. Further, results stemming from this research will identify particular insects with key functional roles that benefit humans. This knowledge could be then be used to identify where to prioritise conservation activities, guide the design and maintenance of green spaces, and assist decision-makers consider insects in broader biodiversity plans and strategies. The study's findings will also provide valuable baseline data that can be integrated into the council's planned research agendas, for example in future iterations of the City of Melbourne's BioBlitz and in the future development of monitoring programs.

Will the project's findings also inform other research agendas?

The study's findings will provide key baseline data to 'The shared urban habitat' research project of the National Environmental Science Programme – Clean Air and Urban Landscapes Hub (Clean Air and Urban Landscapes Hub 2016) and to the Australian Research Council Linkage Project 'Designing green spaces for biodiversity and human well-being' (Bekessy et al. 2016).

Who funded The Little Things that Run the City?

The Little Things that Run the City was funded by the City of Melbourne, RMIT University's Strategic Projects in Urban Research (SPUR) Fund, the Australian Research Council - Centre of Excellence for Environmental Decisions (CEED), and the National Environmental Science Programme - Clean Air and Urban Landscapes Hub (NESP - CAUL).

How is this report different from Mata et al.'s 2015 report entitled 'The Little Things that Run the City – How do Melbourne's green spaces support insect biodiversity and ecosystem health'?

The report presented by Mata et al. (2015) was intended as a preliminary version of the final report we present here. The key difference is that the 2015 report was based on a partial dataset, as only a fraction of the insect material had been sorted by the time the report was developed. It is also important to mention that after the completion

Figure 1.3 The City of Melbourne Central Business District as viewed from one the project's grassland plots in Royal Park.

of the 2015 report the project team decided drop the emphasis on insect orders and to concentrate instead in the key insect groups that are presented in this final report.

Has all the collected data been integrated now into the project's dataset?

Not quite! The project's systematic survey also included the Royal Botanic Gardens Melbourne and the University of Melbourne's System Garden. We also conducted a one-time survey of the Birrarung Marr's flowering meadow. Finally, in addition to insects we also collected spiders. The data derived from these will be the subject of future work.

2 Methodology

Where did the study take place?

The study was conducted in the City of Melbourne (Figure 1.3), a 37.7 km^2 Local Government Area (i.e. municipality) in Victoria, Australia with a residential population of approximately 122,000 people (City of Melbourne 2015).

When did the insect survey take place?

The study took place in the Austral Spring of 2015, from January 6th to March 10th.

How many study sites were included in the study?

15 Argyle Square, Canning/Neill Street Reserve, the area of Carlton Gardens south of the Royal Exhibition Building (henceforth Carlton Gardens South), the combined areas of Fitzroy Gardens and Treasury Gardens (henceforth Fitzroy-Treasury Gardens), Gardiner Reserve, Garrard Street Reserve, Lincoln Square, Murchison Square, Pleasance Gardens, Princes Park, Royal Park, the State Library of Victoria, University Square, Westgate Park and Women's Peace Gardens (Table 2.1; Figure 2.1)

How many plots were established within the study sites?

132

How many habitat types were surveyed?

4 We classified habitat types as tree, mid-storey, grassland or lawn. A detailed description of these is given in Mata et al. (2015).

How was the number and size of plots decided?

We calculated the total area to be surveyed for each habitat type in each green space site using a logarithmic function closely related to the species-area relationship:

$P_h = 100 \cdot 2^{(\log_{10} S) - 3}$

where P_h equals the total area to be surveyed of habitat type *h* and *S* is the area of the green space site. This formula satisfies the condition that the total area to be surveyed of a given habitat type in a 1,000 m^2 site is 100 m^2 (10%), whilst yielding proportionally smaller survey areas as site size increases.

We determined the size of each plot (P_s) with:

$P_s = S/P_n$

where P_n (number of plots per site) was defined as:

$P_n = Integer\ (S/10)$

This specification allowed plot size to vary between 75 m^2 and 150 m^2, and the number of plots of each habitat type to be established in each site to vary between 1 and 9. Values for S, P_h, P_s and P_n are given in Table 2.1.

How many times was each plot surveyed?

3 The time between one survey period and the next was approximately 30 days.

How many plant species were surveyed?

108 These species belonged in 89 genera and 51 families of flowering plants. Lawns, which were dominated by the non-native couch grass *Cynodon dactylon* and kikuyu grass *Pennisetum clandestinum* (Mata et al. 2015), were treated as a single 'lawn complex' species. Likewise, two grassland plots in Royal Park were treated a single 'grassland mix' species. Plants were identified by Anna Backstrom.

Which insect survey methods were used?

Direct observations and sweep-netting (Figure 2.2). These are explained in full detail in Mata et al. (2015).

Figure 2.1 (Opposite page) Geographical location of the fifteen study sites within the City of Melbourne (Victoria, Australia).

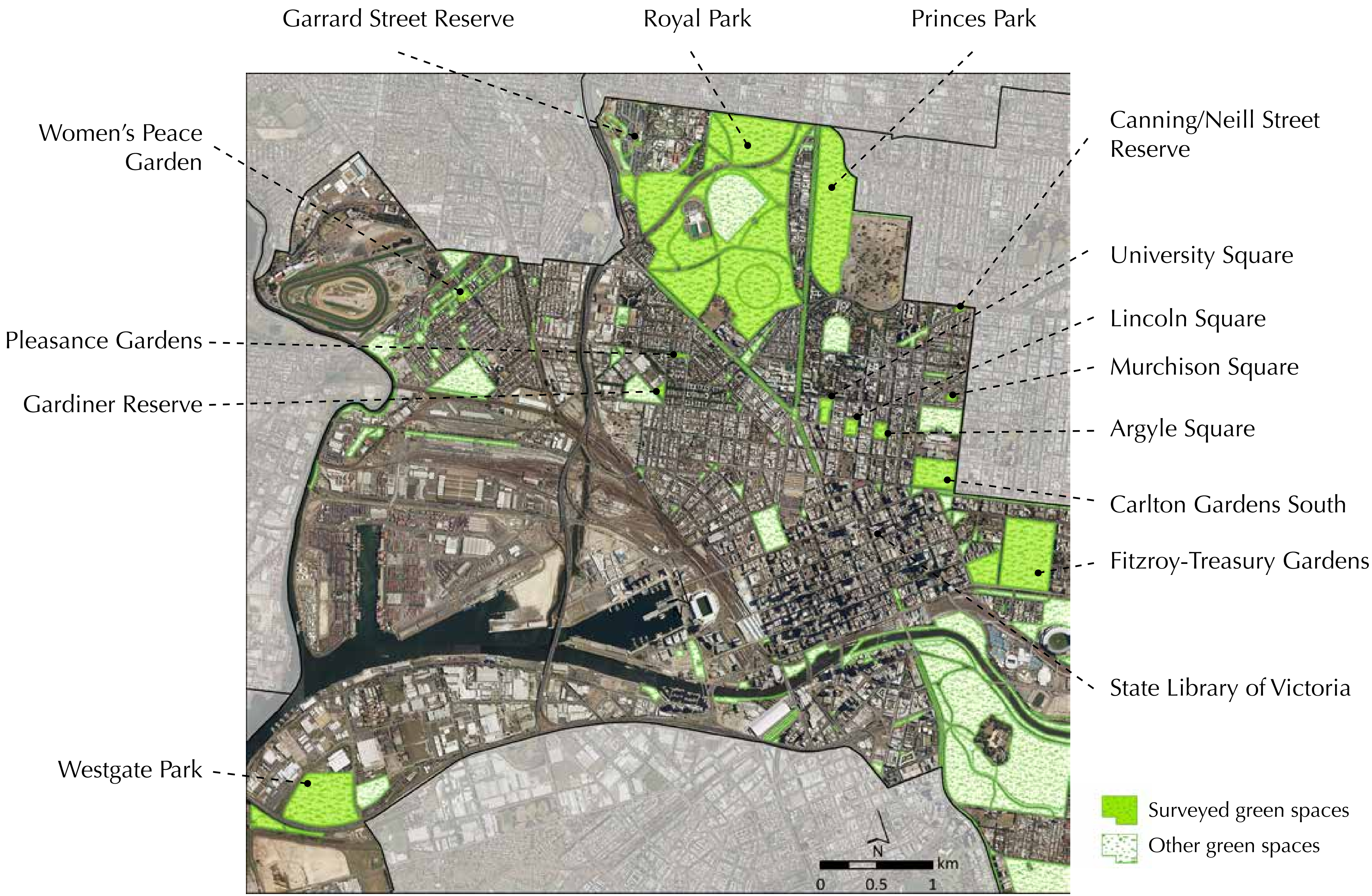
Garrard Street Reserve
Royal Park
Princes Park
Women's Peace Garden
Canning/Neill Street Reserve
University Square
Lincoln Square
Pleasance Gardens
Murchison Square
Gardiner Reserve
Argyle Square
Carlton Gardens South
Fitzroy-Treasury Gardens
State Library of Victoria
Westgate Park
Surveyed green spaces
Other green spaces
N
km
0
0.5
1

Table 2.1 Information on study sites. Habitat types refer to tree (T), mid-storey (MS), grassland (G) and lawn (L). The formulas by which P_h, P_s, and P_n were calculated are given in the text.

Park name	**Total park area (m²)**	**Park area (- impervious surfaces) (m²) [*S*]**	**Total surveyed area (m2) [P_h]**	**Plot size (m²) [P_s]**	**Number of plots [P_n]**	**Habitat types surveyed**	**Total plots established**
Royal Park	1,517,840	1,261,946	858	95	9	All	36
Princes Park	395,620	329,280	573	95	6	All	17
Westgate Park	284,847	239,791	520	104	5	All	20
Fitzroy-Treasury Gardens	321,274	175,776	474	95	5	T, MS, L	15
Carlton Gardens South	88,122	47,244	319	106	3	T, MS, L	9
University Square	16,435	12,768	215	108	2	T, L	3
Lincoln Square	13,264	9,865	199	100	2	T, MS, G, L	6
Argyle Square	12,892	8,335	189	95	2	T, MS, L	6
Women's Peace Garden	6,675	5,684	169	84	2	T, MS, L	6
Gardiner Reserve	5,286	3,655	148	148	1	T, MS, L	3
Pleasance Gardens	3,711	3,404	145	145	1	T, L	2
Murchison Square	3,767	3,294	143	143	1	T, L	2
State Library of Victoria	3,000	2,400	130	130	1	T, MS, L	3
Canning/Neill Street Reserve	1,898	1,601	115	115	1	T, L	2
Garrard Street Reserve	1,159	1,081	102	102	1	T, L	2
							132

How many insect groups were included in the study?

12 These were (common name followed by scientific name of taxa in brackets):

Ants (Hymenoptera: Formicidae)

Bees (Hymenoptera: Apoidea)

Beetles (Coleoptera)

Cicadas (Hemiptera: Cicadoidea)

Flies (Diptera: Brachycera)

Heteropteran bugs (Hemiptera: Heteroptera)

Figure 2.2 One of the authors sweep-netting a grassland plot in Royal Park.

Jumping plant lice (Hemiptera: Psylloidea)

Leafhopper/Treehoppers (Hemiptera: Membracoidea)

Parasitoid wasps (Hymenoptera: Parasitica)

Planthoppers (Hemiptera: Fulgoroidea)

Sawflies (Hymenoptera: Symphyta)

Stinging wasps (Hymenoptera: Aculeata).

How was the insect reference collection built?

Each sample (i.e. a vial containing insect specimens from a given plant/plot/site) was sorted under a binocular microscope (mostly by Kate Cranney and Tessa Smith, but also by Laura Stark and Luis Mata) to order and then to morphospecies. One or more representatives of each morphospecies were placed into the project's reference collection. Duplicate material was stored in 70% ethanol. Morphospecies were assigned a unique code starting with the first three letters of the order that they belonged to (e.g. hem001).

Who identified the insects?

Alan Andersen (ants), Daniel Bickel (flies), Mali Malipatil (heteropteran bugs), Luis Mata (heteropteran bugs), Melinda Moir (heteropteran bugs and jumping plant lice), Nick Porch (beetles) with help from Rolf Oberprieler, Adam Slipinski and Chris Reid for selected unknown weevils, ladybirds and leaf beetles, respectively, Linda Semeraro (leafhopper, treehoppers and planthoppers) and Ken Walker (bees and wasps).

3 Findings

How many insect species were recorded in the study?

560 These belonged in 104 families (Table 3.1).

Which insect group had the highest diversity of species?

Beetles (Figures 3.1 and 3.2), followed by parasitoid wasps and flies (Table 3.1; Figure 3.3).

Was the most common species in the study also a beetle?

Yes It was a 'Minute brown scavenger beetle' in genus *Cortinicara*. It accounted for almost 12% of all records (Figure 3.4). This species was reported in Mata et al. (2015) as *Corticaria sp. 1*. Minute brown scavenger beetles are tiny and dark, and measure about 2 mm in length (Figure 3.5). Truly ubiquitous in the City of Melbourne, the species was collected in all fifteen sites, in as much as 83% of all plots, in the four studied habitat types and in association with 102 different plant species (that is 94% of all surveyed plant species!). Both adults and immature stages are scavengers and fungivores (Andrews 2002).

Which was the most common fly species?

The lawn fly *Hydrellia tritici* was the most frequently recorded fly, accounting for over 6% of all records (Figure 3.4). The lawn fly (Figure 3.6) is one of the most common flies in Australia (Marshall 2012).

Which was the most common ant species?

Iridomyrmex sp. 1 was the most frequently recorded ant, accounting for almost 5% of all records (Figure 3.4). Our *Iridomyrmex sp. 1* is in fact a complex of species (Alan Andersen personal communication), including *Iridomyrmex septentrionalis*, *Iridomyrmex suchieri*, *Iridomyrmex sp.* (splendens group) and *Iridomyrmex sp.* (bicknelli group). *Iridomyrmex*

Table 3.1 Number of insect species and families recorded in each insect group.

		Species	Families
Beetles	Coleoptera	127	30
Parasitoid wasps	Parasitica	124	10
Flies	Brachycera	107	24
Heteropteran bugs	Heteroptera	61	14
Leafhoppers/Treehoppers	Membracoidea	40	2
Jumping plant lice	Psylloidea	31	3
Stinging wasps	Aculeata	23	9
Ants	Formicidae	17	1
Bees	Apoidea	16	5
Planthoppers	Fulgoroidea	11	4
Sawflies	Symphyta	2	1
Cicadas	Cicadoidea	1	1
		560	**104**

species (Figure 3.7) are generalist predators and scavengers that supplement their diets with honeydew and nectar. They are also known to consume 'elaiosomes' (fleshy nutritious structures attached to seeds). By moving the elaiosome-bearing seeds into the nest to feed larvae, *Iridomyrmex* species contribute to seed dispersal.

Which was the most common leafhopper species?

An erythroneurinid leafhopper [Erythroneurini 1] was the most frequently recorded leafhopper, accounting for approximately 4% of all records (Figure 3.4). This species was reported in Mata et al. (2015) as an empoascine leafhopper [Typhlocybinae 2]. Erythroneurini 1 is very likely a species in genus *Anzygina* (Figure 3.8). Erythroneurinid leafhoppers are herbivores specialised in parenchyma feeding (Fletcher 2009).

Which was the most common heteropteran bug species?

The Rutherglen bug *Nysius vinitor* was the most frequently recorded heteropteran bug, accounting for about 2% of all records (Figure 3.4). The Rutherglen bug (Figure 3.9) is a generalist herbivore (Malipatil 2007).

Which was the most frequently recorded planthopper species?

The grey planthopper *Anzora unicolor* (Figure 3.10) was the most frequently recorded planthopper, accounting for approximately 1% of all records (Figure 3.4).

Which was the most common parasitoid wasp species?

A diapriid wasp [Diapriidae 4] was the most frequently recorded parasitoid wasp in the study (Figure 3.4). As with many other parasitoid wasps (Figure 3.11), the immature stages of diapriid wasps develop inside insect hosts, for example a fly's larva or pupa, which they eventually consume as food (Masner 1993). This capacity to regulate insect populations means that diapriids, as well as all other parasitoid wasps, are important providers of biological pest control.

Which was the most common bee species?

The European honey bee *Apis mellifera* was the most frequently recorded bee in the study (Figure 3.4). The European honey bee (Figure 3.12) is a specialised pollinator that is non-native to Australia.

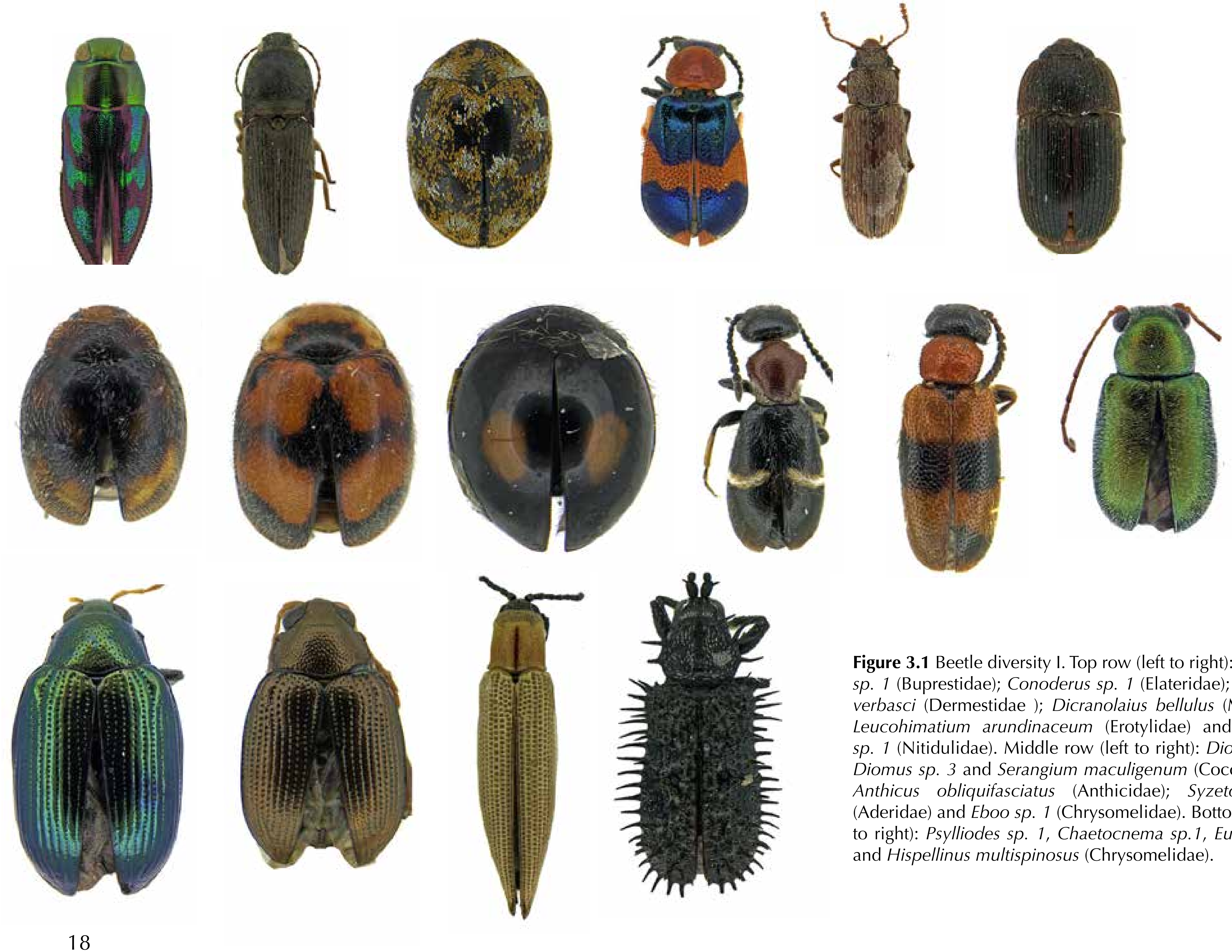

Figure 3.1 Beetle diversity I. Top row (left to right): *Melobasis sp. 1* (Buprestidae); *Conoderus sp. 1* (Elateridae); *Anthrenus verbasci* (Dermestidae); *Dicranolaius bellulus* (Melyridae); *Leucohimatium arundinaceum* (Erotylidae) and *Idaethina sp. 1* (Nitidulidae). Middle row (left to right): *Diomus sp. 1*, *Diomus sp. 3* and *Serangium maculigenum* (Coccinellidae); *Anthicus obliquifasciatus* (Anthicidae); *Syzeton sp. 1* (Aderidae) and *Eboo sp. 1* (Chrysomelidae). Bottom row (left to right): *Psylliodes sp. 1*, *Chaetocnema sp.1*, *Eurispa sp. 1* and *Hispellinus multispinosus* (Chrysomelidae).

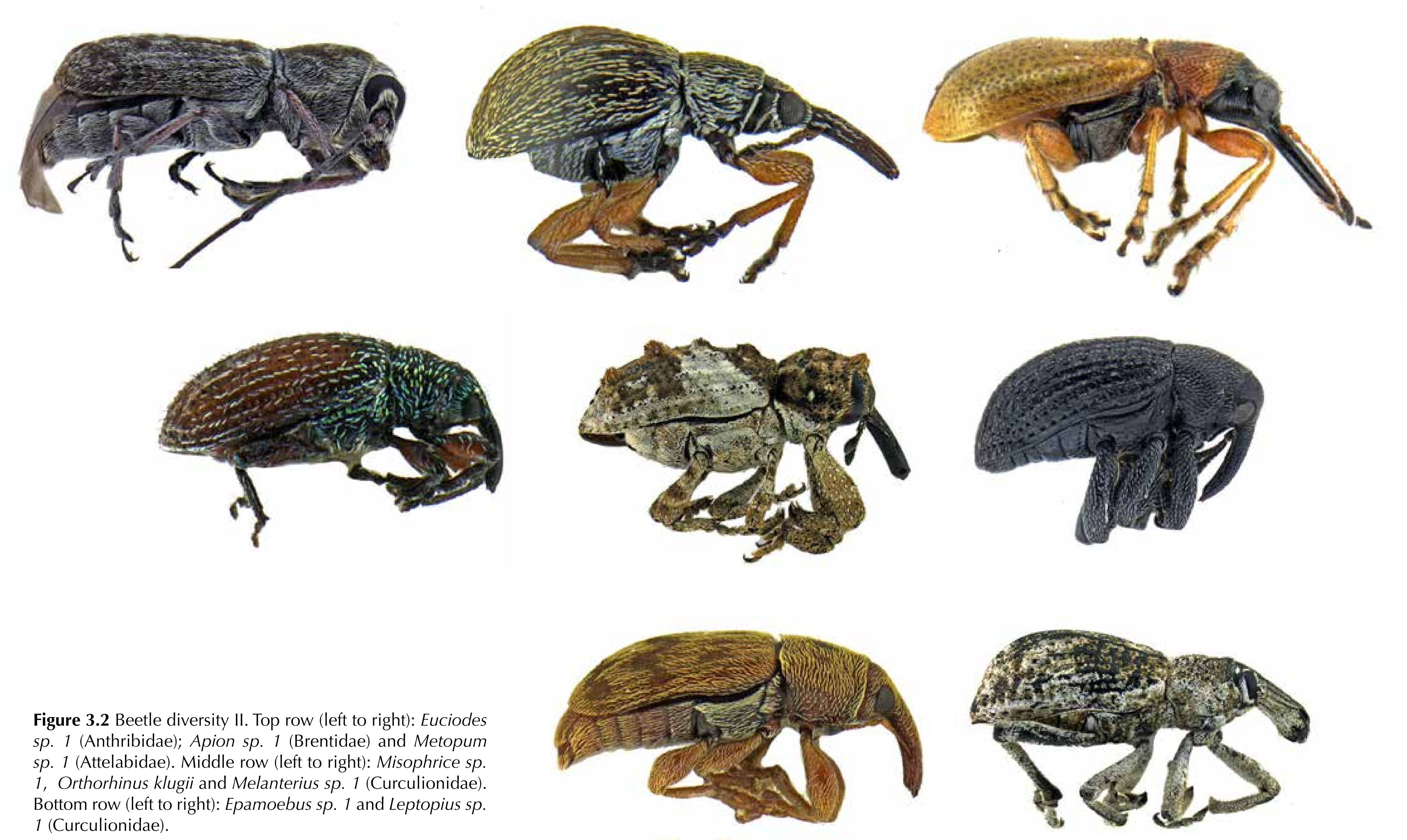

Figure 3.2 Beetle diversity II. Top row (left to right): *Euciodes sp. 1* (Anthribidae); *Apion sp. 1* (Brentidae) and *Metopum sp. 1* (Attelabidae). Middle row (left to right): *Misophrice sp. 1*, *Orthorhinus klugii* and *Melanterius sp. 1* (Curculionidae). Bottom row (left to right): *Epamoebus sp. 1* and *Leptopius sp. 1* (Curculionidae).

How many native bee species were recorded in the study?

13 They were: a species in genus *Hylaeus*, *Lasioglossum clelandi*, *Homalictus sphecodoides*, *Hyphesma atromicans*, *Homalictus punctatus*, *Homalictus bisbanensis*, a species in genus *Euryglossina*, a species in genus *Callohesma*, *Lasioglossum hemichalceum*, *Lasioglossum cognatum*, *Lasioglossum quadratum*, *Lipotriches flavoviridis*, and a species in family Colletidae awaiting genus/species identification.

How common were stinging wasps?

Stinging wasps represented approximately 2% off all records. They included native species of bethylidid wasps, cuckoo wasps, dryinidid wasps (Figure 3.13), velvet ants, spider wasps, scoliid wasps, tiphiid wasps, as well as the non-native European wasps *Vespula germanica* (Figure 3.14)

How common were jumping plant lice?

Jumping plant lice represented over 2% of all records. They included species in the genera *Aacanthocnema*, *Acanthocasuarina*, *Acizzia*, *Anoeconessa*, *Blastopsylla*, *Boreioglycaspis*, *Cardiaspina*, *Creiis*, *Cryptoneossa*, *Ctenarytaina*, *Dasypsylla*, *Eucalyptolyma* , *Glycaspis*, *Mycopsylla*, *Phellopsylla*, *Phyllolyma* and *Platyobria*. As much as 90% of all jumping plant louse species recorded in the study were found living in association with native plant species. While in their immature stages, some jumping plant louse species produce lerps - protective crystallised structures made out of the insect's sugary honeydew (Carver et al. 1991). Some jumping plant louse species are tended by ants (Cover image and Figure 3.15).

How many sawfly species were recorded?

2 Both species belonged in family Pergidae. The caterpillar-like larvae of sawflies are herbivores, feeding on the plant species in which they were born (Figure 3.16).

How many cicada species were found?

1 It was found in Royal Park living in association with *Melaleuca viminalis*.

How many insect species were observed only once throughout the entire study?

219 That is approximately 40% of all species recorded in the study. This aligns well with many other insect surveys in which 30-40% of all

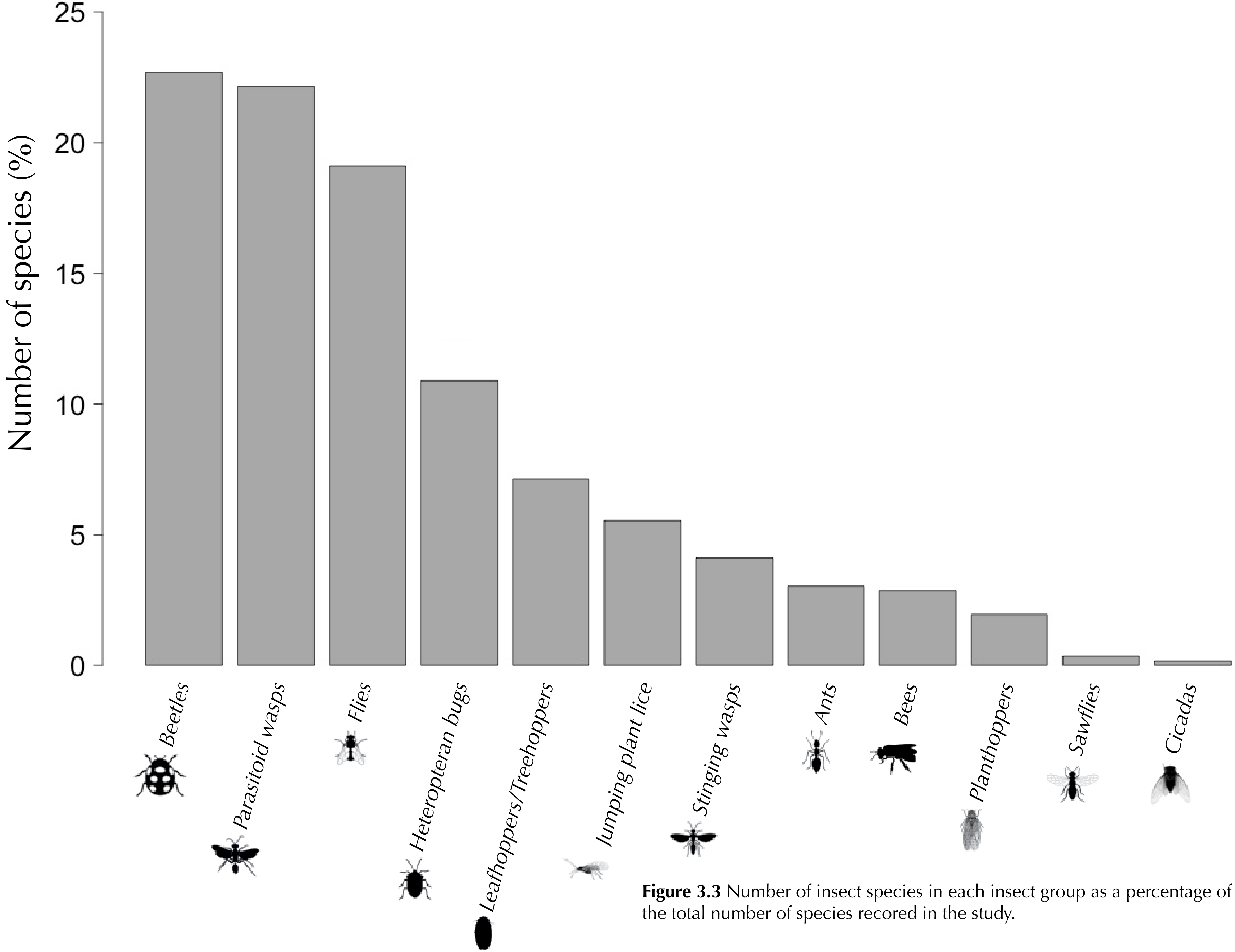

Figure 3.3 Number of insect species in each insect group as a percentage of the total number of species recored in the study.

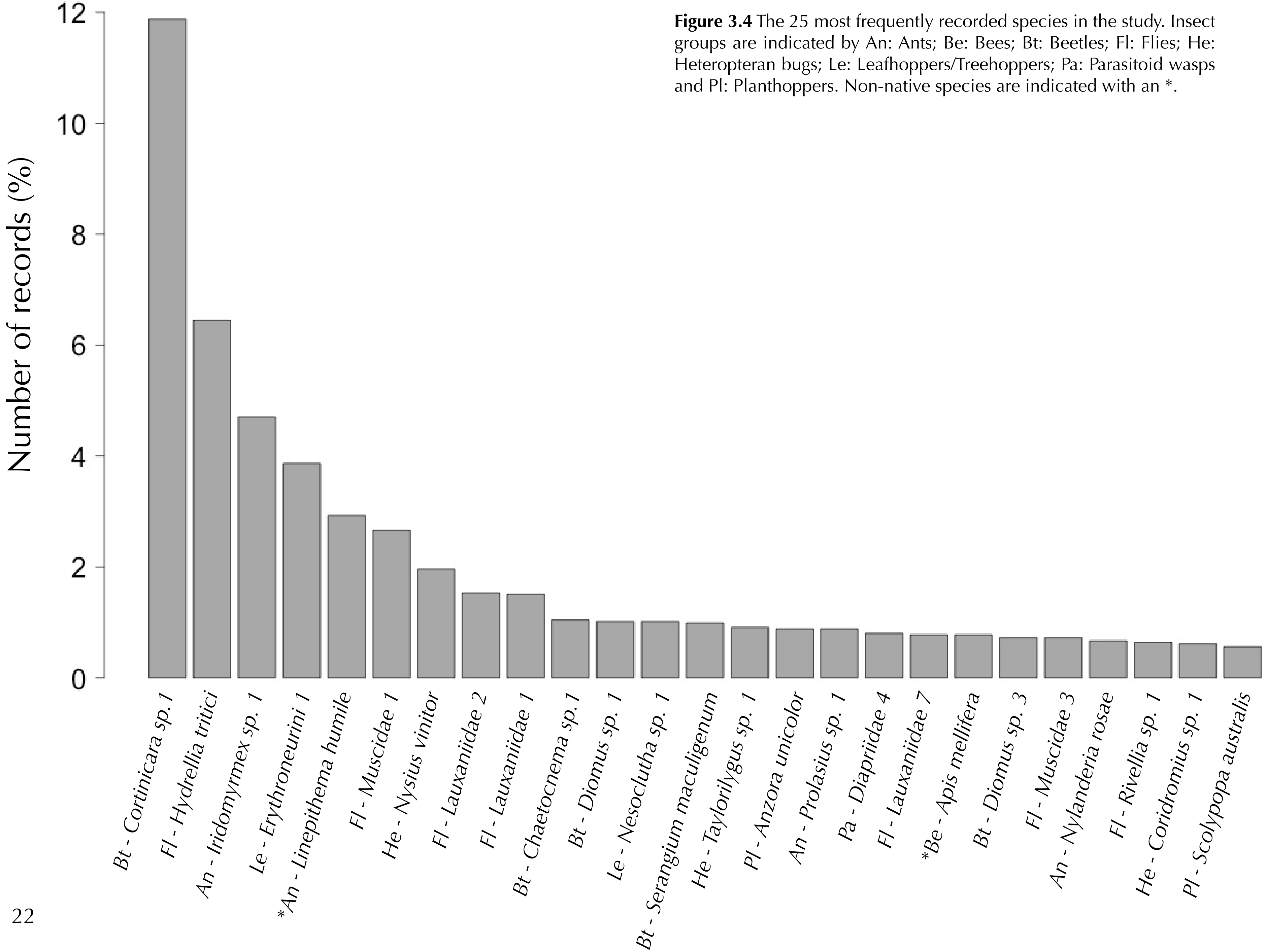

Figure 3.4 The 25 most frequently recorded species in the study. Insect groups are indicated by An: Ants; Be: Bees; Bt: Beetles; Fl: Flies; He: Heteropteran bugs; Le: Leafhoppers/Treehoppers; Pa: Parasitoid wasps and Pl: Planthoppers. Non-native species are indicated with an *.

Figure 3.5 Minute brown scavenger beetle *Cortinicara sp. 1*.

Figure 3.6 The lawn fly *Hydrellia tritici*.

Figure 3.7 A rainbow ant *Iridomyrmex sp.*
Photo by: Steve Shattuck.

documented species are recorded only once.

Did the survey yield any particularly interesting uncommon species?

Yes Dryinidid wasps (Figure 3.13), which have been recorded very few times in Victoria. Other interesting examples were the seed bug *Eurynysius meschioides* and the chinch bug *Heinsius sp. 1* (both heteropteran bugs), which were discussed in detail in Mata et al. (2015).

Did the survey yielded any new species for science?

Yes Four new species to science have been found thus far in our study. We found a new species of ant belonging in genus *Turneria* (Alan Andersen personal communication) living on ironbark *Eucalyptus sideroxylon* in Princess Park. A mounted specimen of this new species is shown in Figure 3.17. We also found a new species of lacebug – a heteropteran bug in family Tingidae – living on brush box *Lophostemon confertus* and bracelet honey myrtle *Melaleuca armillaris* (Fitzroy-Treasury Gardens, Princes Park and Royal Park). The Fitzroy-Treasury Gardens' brush box specimen that was surveyed by direct observation is shown in Figure 3.18. Finally, we found two new species of jumping plant lice: *Mycopsylla sp. nov.* (tuberculata group) living on Moreton Bay fig *Ficus macrophylla* (Carlton Gardens South, Fitzroy-Treasury Gardens Lincoln Square and Princess Park); and *Acanthocasuarina sp. nov.* (muellerianae group) living on tussock-grass *Poa labillardierei*, fragrant Saltbush *Chenopodium parabolicum* and

Figure 3.8 (above) An erythroneurinid leafhopper en genus *Anzygina*. Photo by Tony Daley.

Figure 3.9 (opposite page) The Rutherglen bug *Nysius vinitor.*

Figure 3.10 The grey planthopper *Anzara unicolor*.
Photo by Patrick Calmels.

Figure 3.11 A parasitoid wasp.
Photo by James Dorey.

Figure 3.12 The European honey bee *Apis mellifera* visiting the flower of a spotted gum (*Corymbia maculata*) in Royal Park.

Figure 3.13 A dryinidid wasp found in Royal Park on the common boobialla *Myoporum insulare*.

drooping Sheoak *Allocasuarina verticillata* (all in Royal Park).

Did you observe any interesting species from the insect groups you were studying outside of the targeted survey?

Yes In Royal Park we saw the chequered cuckoo bee *Thyreus caeruleopunctatus* (Figure 3.19A), a hunchback fly in genus *Ogcodes* (Figure 3.19B), a blue-banded fly in genus *Trigonospila* (Figure 3.19C), the cowboy beetle *Chondropyga dorsalis* (Figure 3.19D), the long-tailed sawfly *Pterygophorus facielongus* (Figure 3.16), and the blue-banded bee *Amegilla asserta* - buzzing around the black-anther flax-lily *Dianella admixta* (Figure 3.20). In

Figure 3.14 (below) The European wasp *Vespula germanica*. Photo by Jon Sullivan.

Figure 3.15 (opposite page) An ant tending a jumping plant louse's lerp.

Figure 3.16 Larvae of the long-tailed sawfly *Pterygophorus facielongus* skeletonising a leaf in Royal Park.

Figure 3.17 A stacked macro-photograph of *Turneria sp. nov.*
Photo courtesy of Alan Andersen.

Figure 3.18 The lacebug *Tingis sp. nov.* on brush box *Lophostemon confertus*.

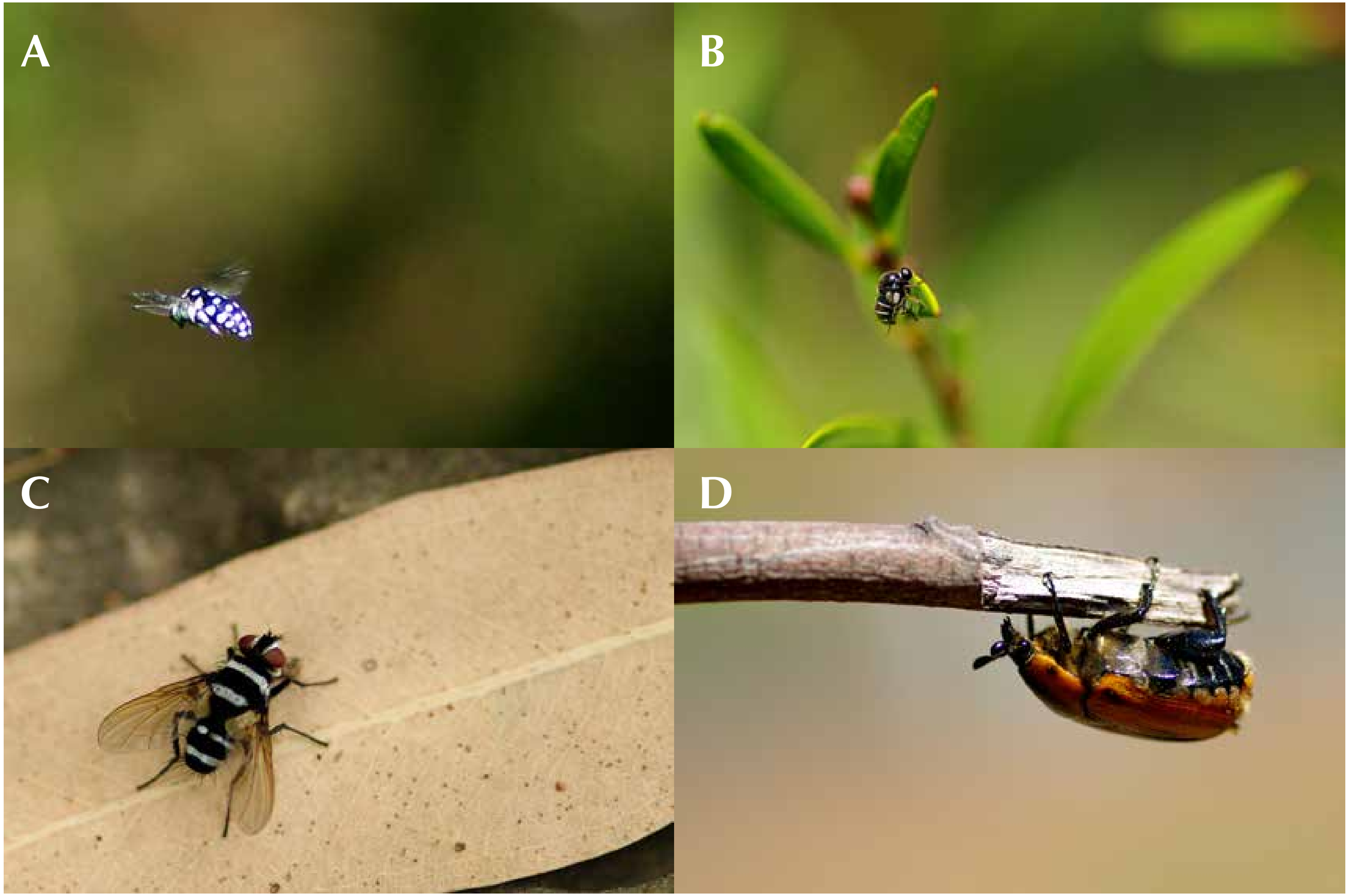

Figure 3.19 A Chequered cuckoo bee *Thyreus caeruleopunctatus*. **B** Hunchback fly in genus *Ogcodes*. **C** Blue-banded fly in genus *Trigonospila*. **D** Cowboy beetle *Chondropyga dorsalis*. All photos from Royal Park.

Figure 3.20 A blue-banded bee *Amegilla asserta* buzzing around the black-anther flax-lily *Dianella admixta* in Royal Park.

Royal Park and Westgate Park we further observed leafcutter bees in genus *Megachile* (Figure 3.21).

How many of the insect species found were native to Australia?

541 That is about 97% of all recorded species in the study.

Which was the most common non-native species?

The Argentine ant *Linepithema humile* (Figure 3.22) represented approximately 3% of all records and as much as quarter of all insect records. This is an aggressive invasive species that may displace native ant species (e.g. species in genus *Iridomyrmex*), and therefore capable of disrupting ant-mediated seed dispersal interactions (Rowles and O'Dowd 2009). It was one of 19 non-native species recorded in the study, the other species being: a sap beetle [*Meligethes sp. 1*], the elm leaf beetle *Xanthogaleruca luteola*, the bronze leaf beetle *Diachus auratus*, the small striped flea beetle *Phyllotreta undulata*, eight weevils (*Naupactus cervinus*, *Naupactus leucoloma, Listronotus sp. 1* (bonariensis group), *Apinocis variipennis*, *Phlyctinus callosus*, *Sitona discoideus*, the Flores weevil *Atrichonotus sordidus* and a dereleminid weevil [Derelomini 1]), the spotted amber ladybird *Hippodamia variegata* (Figure 3.23), the black lawn beetle *Heteronychus arator,* the lizard beetle *Leucohimatium arundinaceum*, an archaeocrypticid beetle *Archaeocrypticus topali*, the European honey bee *Apis mellifera* (Figure 3.12) and the European wasp *Vespula germanica* (Figure 3.14).

Which green space site had the highest number of insect species?

Royal Park A total of 354 insect species were recorded in Royal Park, which means that over 60% of all documented species occur in this green space (Figure 3.24). With 186 species, Westgate Park was the green space with the second highest species richness, followed by Princes Park, in which 176 species were recorded. The number of species per insect group in each study site is given in Table 3.2.

Which habitat type had the highest insect species richness?

Mid-storey A total of 337 insect species were recorded in mid-storey plots, which means that as much as 60% of all documented species occurred in this type of habitat (Figure 3.25). The second most diverse habitat type was tree (over

Figure 3.21 A leafcutter bee in genus *Megachile*. Photo from Westgate Park.

Figure 3.22 The Argentine ant *Linepithema humile*.
Photo by Juan Carlos Bernal.

Figure 3.23 The amber spotted ladybird *Hippodamia variegata*.

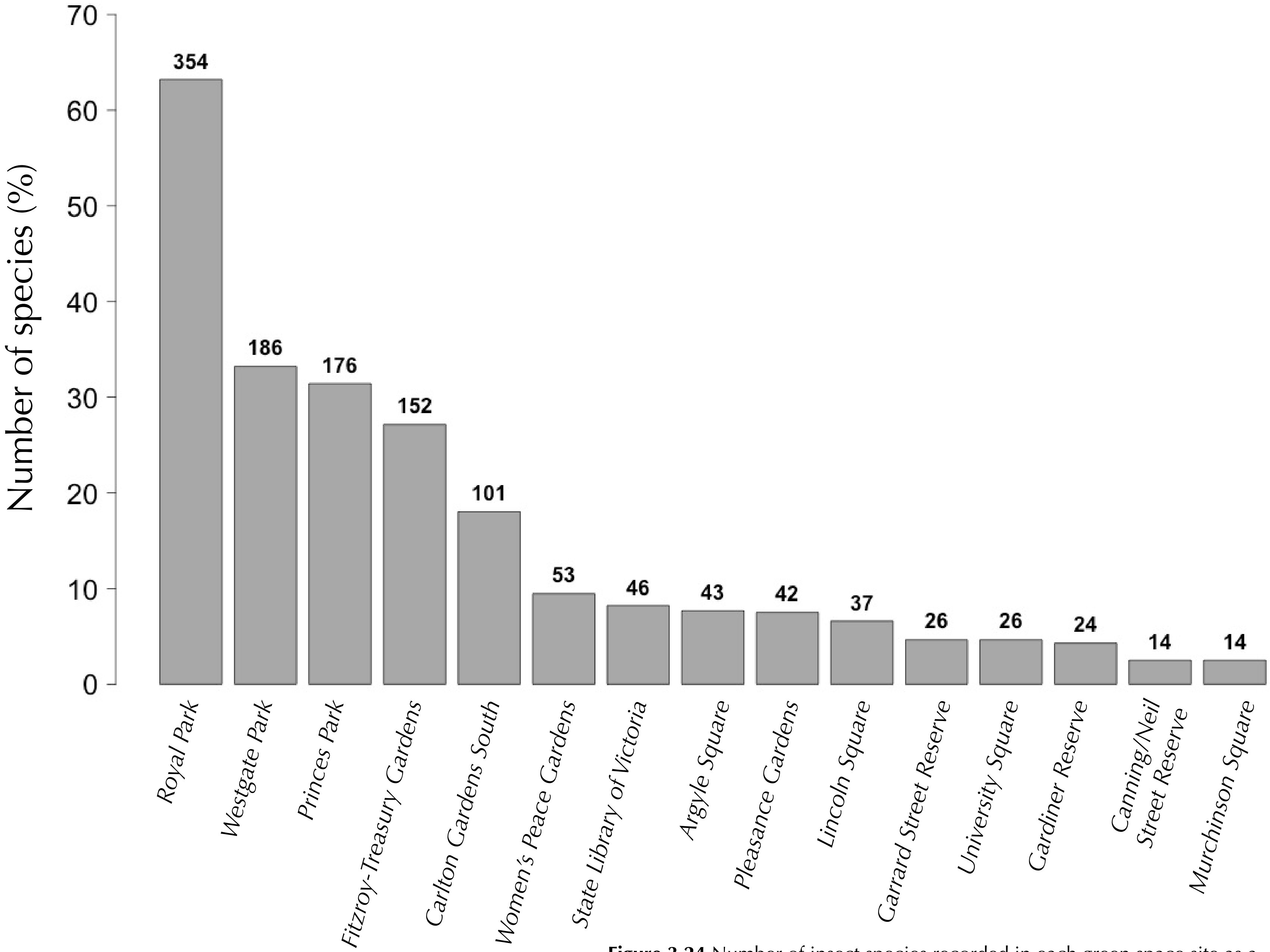

Figure 3.24 Number of insect species recorded in each green space site as a percentage of the total number of species recored in the study. Bold numbers in top of each bar indicate the total number of insect species recorded in each site.

50% of all records), followed by grassland (38%). The habitat type with the least number of associated insect species was lawn, in which only 19% of all insect species were found.

Which habitat type had the highest number of unique insect species?

Mid-storey As many as 127 species were recorded exclusively in mid-storey plots (Figure 3.26). The tree and grassland habitat types had 111 and 63 unique species, respectively. The habitat type with the least number of unique species was lawn (15 species).

How many insect species were recorded in all four habitat types?

41 These included amongst others the minute brown scavenger beetle *Cortinicara sp. 1* (Figure 3.5), the spotted amber ladybird *Hippodamia variegata* (Figure 3.23), the Rutherglen bug *Nysius vinitor* (Figure 3.9), ants in the *Iridomyrmex* complex (Figure 3.7), the Argentine ant *Linepithema humile* (Figure 3.22), the lawn fly *Hydrellia tritici* (Figure 3.6) and the Pacific damsel bug *Nabis kinbergii* (Figure 3.27).

Which plant species had the highest number of associated insect species?

The tussock-grass A total of 103 insect species were associated with tussock-grass *Poa labillardierei*, or in other words as much as 18% of all recorded insect species occurred in this one plant species (Figure 3.28). The tussock-grass *Poa labillardierei* (Figure 3.29) is a perennial tussock grass native to southern and eastern Australia (Sharp and Simon 2002). The native wallaby (*Rytidosperma sp.*) and kangaroo (*Themeda triandra*) grasses also had large number of associated insect species (71 and 62, respectively; Figure 3.28).

Which shrub species had the highest number of associated insect species?

The shrub with the highest number of associated insect species (103; Figure 3.28) was the fragrant saltbush *Chenopodium parabolicum* (formerly known as *Rhagodia parabolica*). The native shrubs sweet bursaria *Bursaria spinosa*, gold-dust wattle *Acacia acinacea* and hop goodenia *Goodenia ovata* also had large number of associated insect species (56, 54 and 45; Figure 3.28).

Table 3.2 Number of insect species per insect group recorded in each green space.

		Royal Park	Westgate Park	Princes Park	Fitzroy-Treasury Gardens	Carlton Gardens South	Women's Peace Gardens	State Library of Victoria	Argyle Square	Pleasance Gardens	Lincoln Square	Garrard Street Reserve	University Square	Gardiner Reserve	Canning/Neil Street Reserve	Murchinson Square
Beetles	Coleoptera	78	49	42	33	25	6	6	8	5	3	8	4	3	2	3
Parasitoid wasps	Parasitica	67	33	37	32	11	5	6	2	9	4	7	3	4	2	0
Flies	Brachycera	78	49	33	47	34	19	20	15	15	16	3	6	7	4	5
Heteropteran bugs	Heteroptera	31	22	20	13	14	6	5	8	4	5	3	2	2	2	2
Leafhoppers/Treehoppers	Membracoidea	25	11	12	2	4	6	5	2	3	2	1	4	2	1	2
Jumping plant lice	Psylloidea	20	5	9	5	2	0	0	1	0	1	2	0	0	0	0
Stinging wasps	Aculeata	18	4	8	5	1	2	0	1	0	0	0	3	2	0	0
Ants	Formicidae	16	5	10	10	5	5	4	5	4	4	1	3	4	2	2
Bees	Apoidea	11	5	1	2	4	2	0	1	1	1	0	0	0	1	0
Planthoppers	Fulgoroidea	9	2	12	3	1	2	5	0	0	1	1	1	0	0	0
Sawflies	Symphyta	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Cicadas	Cicadoidea	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		354	**186**	**176**	**152**	**101**	**53**	**46**	**43**	**42**	**37**	**26**	**26**	**24**	**14**	**14**

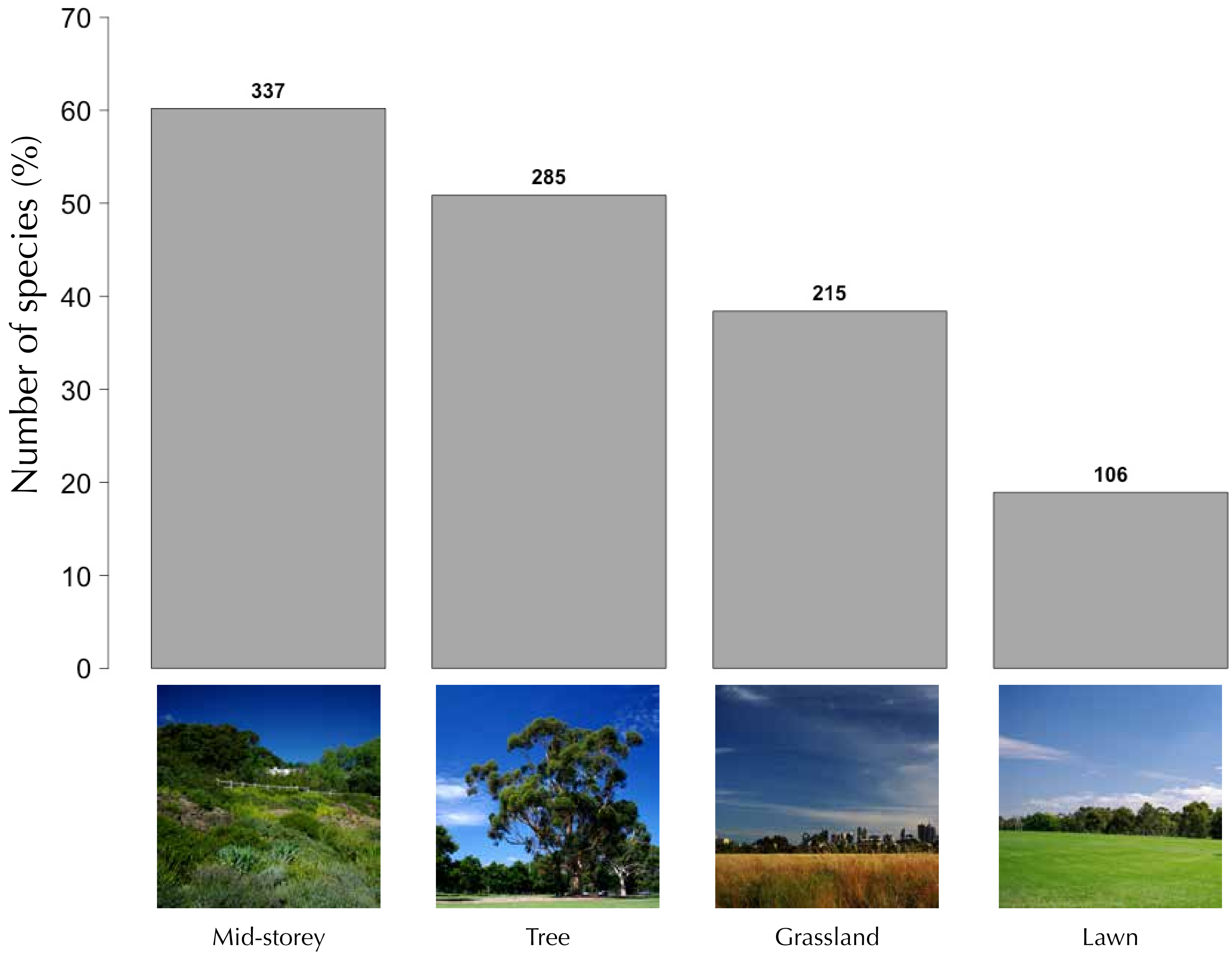

Figure 3.25 Number of insect species recorded in each habitat type as a percentage of the total number of species recored in the study. Bold numbers in top of each bar indicate the total number of insect species recorded in habitat type.

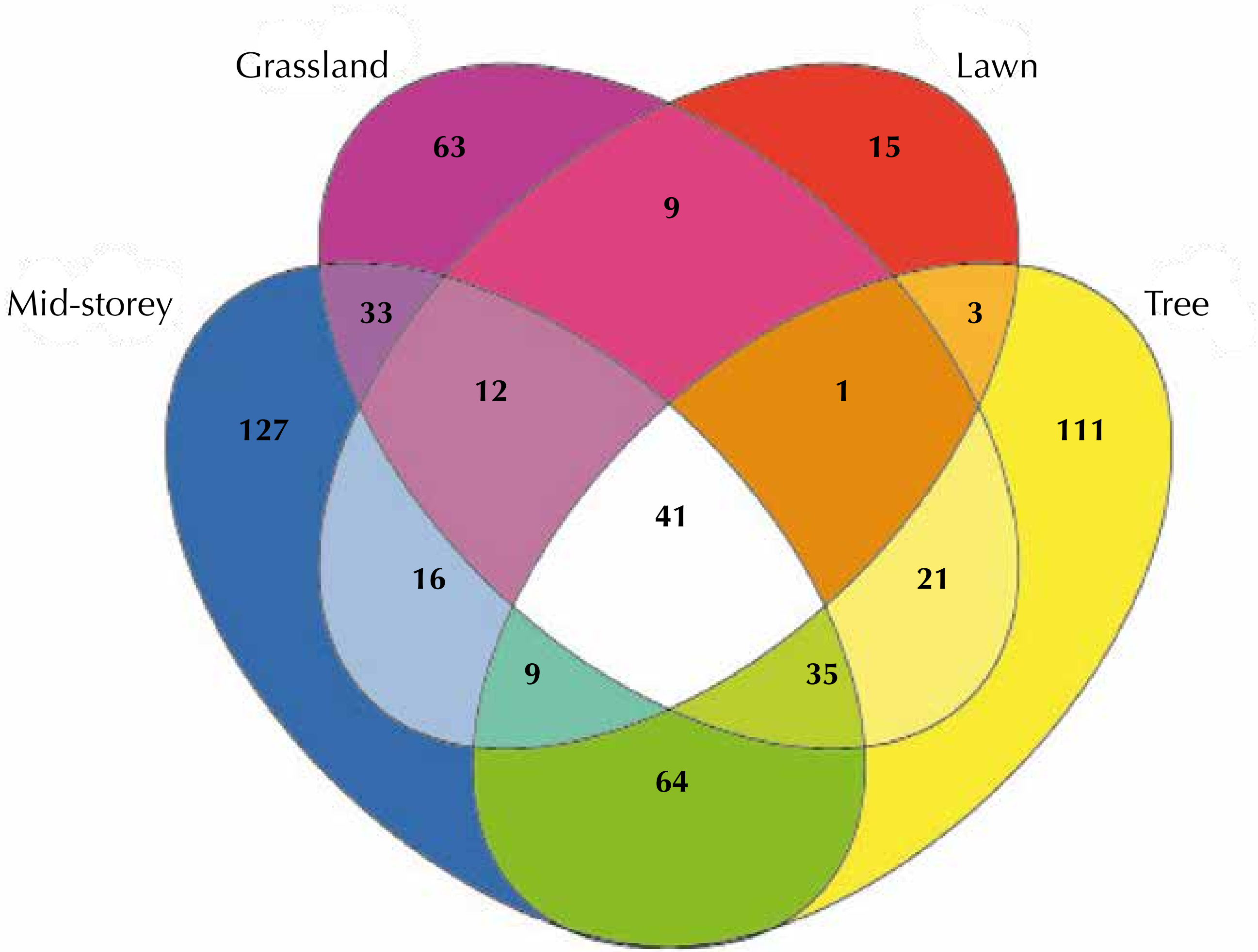

Figure 3.26 A Venn diagram showing the distribution of insect species amongst mid-storey, grassland, lawn and tree habitat types. The non-intersecting areas indicate the number of unique species. The intersecting areas indicate the number of shared species. The white area in the centre of the diagram indicates the number of species that were common to all four habitat types.

Figure 3.27 The Pacific damsel bug *Nabis kinbergii*.

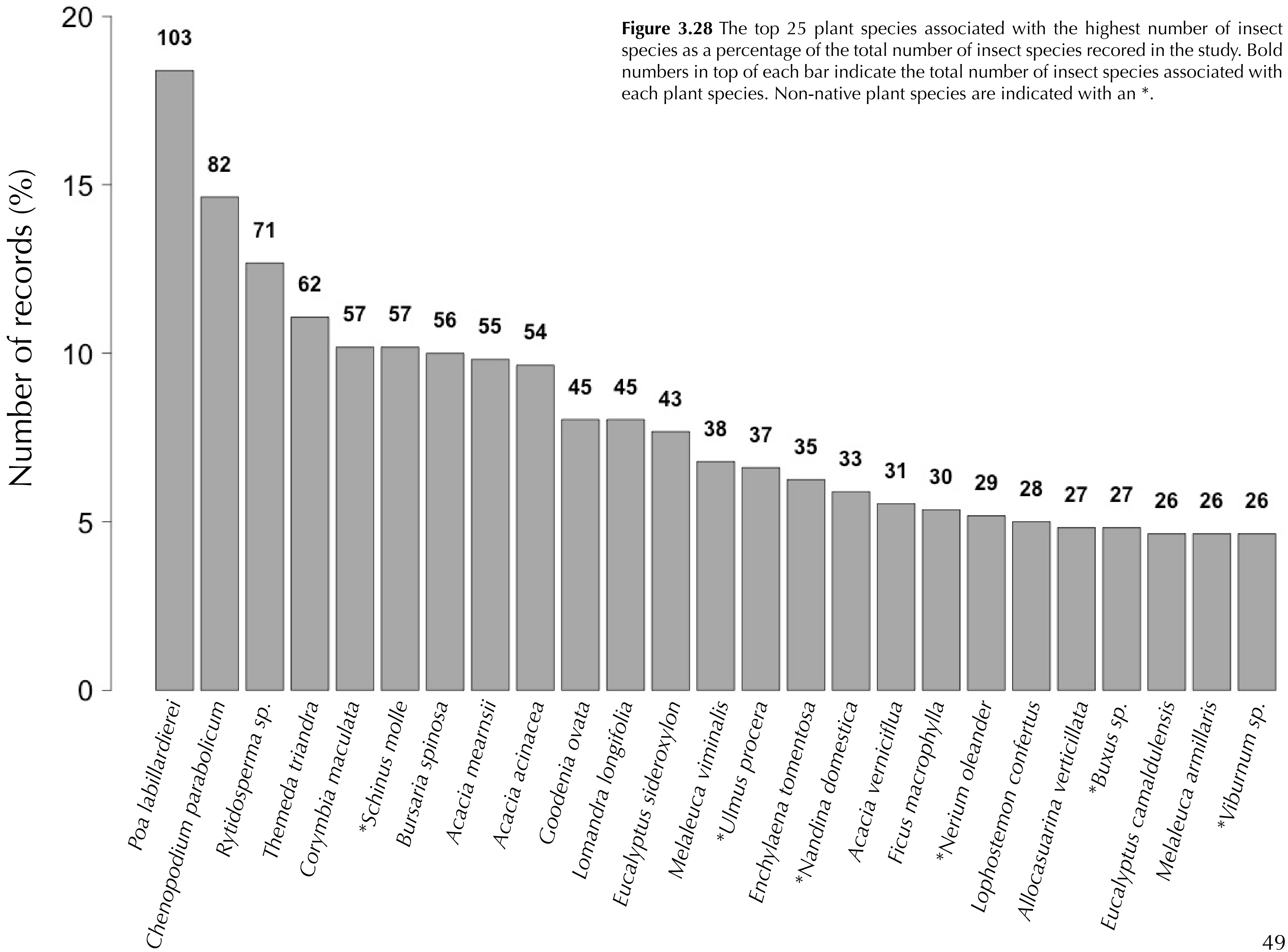

Figure 3.28 The top 25 plant species associated with the highest number of insect species as a percentage of the total number of insect species recored in the study. Bold numbers in top of each bar indicate the total number of insect species associated with each plant species. Non-native plant species are indicated with an *.

Figure 3.29 The tussock-grass *Poa labillardierei*.
Photo by Nathan Johnson.

Which tree species had the highest number of associated insect species?

The tree species with the highest number of associated insect species (57; Figure 3.28) were the native spotted gum *Corymbia maculata* (Figures 3.12 and 3.30) and the non-native pepper tree *Schinus molle* (an evergreen tree native to the American Andes). The native trees black wattle *Acacia mearnsii* and ironbark *Eucalyptus sideroxylon* also had large number of associated insect species (55 and 43, respectively; Figure 3.28).

Taken together, were there more insect species in native or non-native tree species?

On average, there were over 60% more insect species in native than non-native tree species.

How many associations between insect and plant species were documented?

2191 Given that the total number of all possible associations between insect and plant species in our study was 60,480 (560 insect species times

Figure 3.30 A spotted gum *Corymbia maculata* in Royal Park.

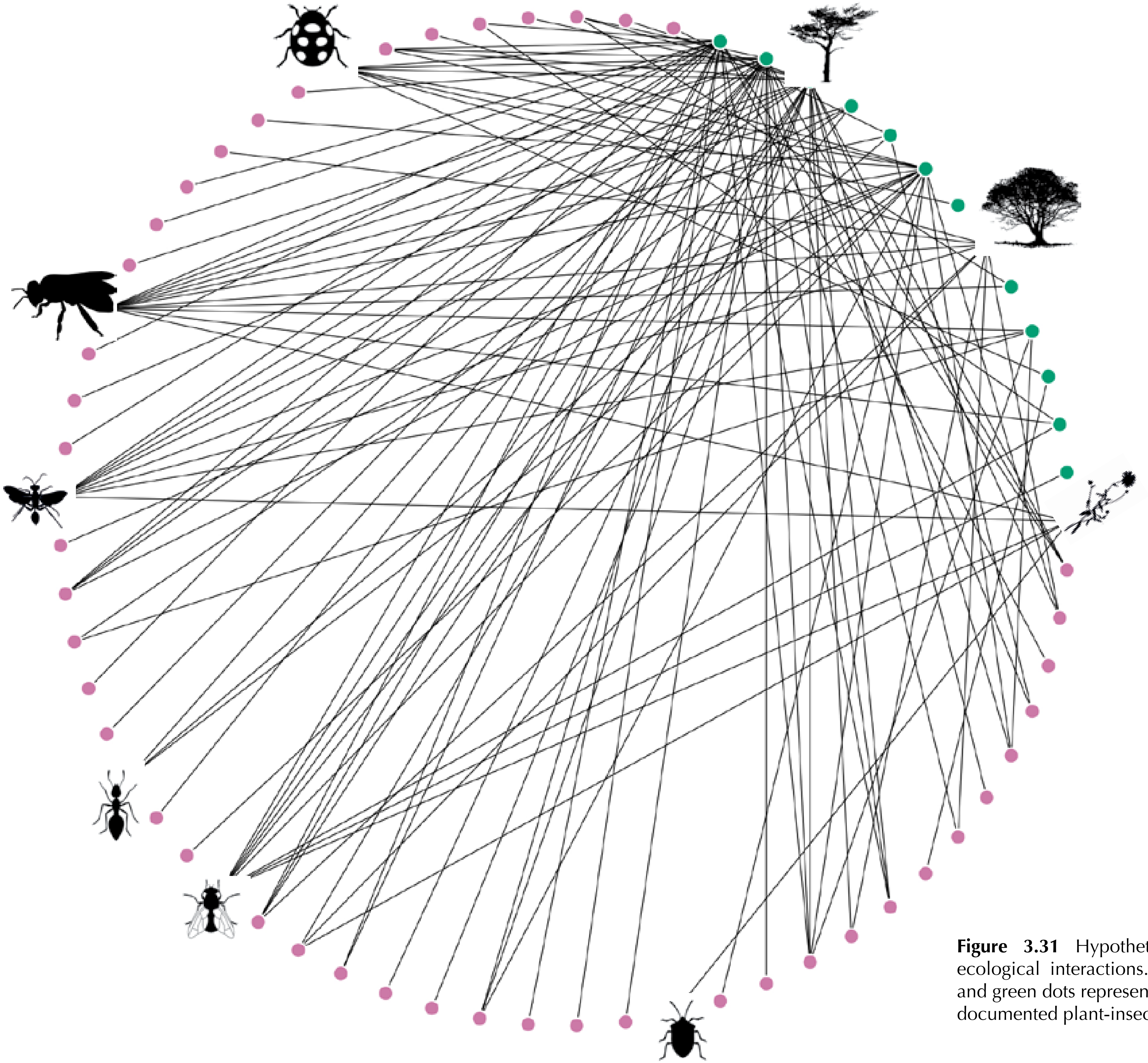

Figure 3.31 Hypothetical metanetwork of plant-insect ecological interactions. Red dots represent insect species and green dots represent plant species. Each line represent a documented plant-insect association.

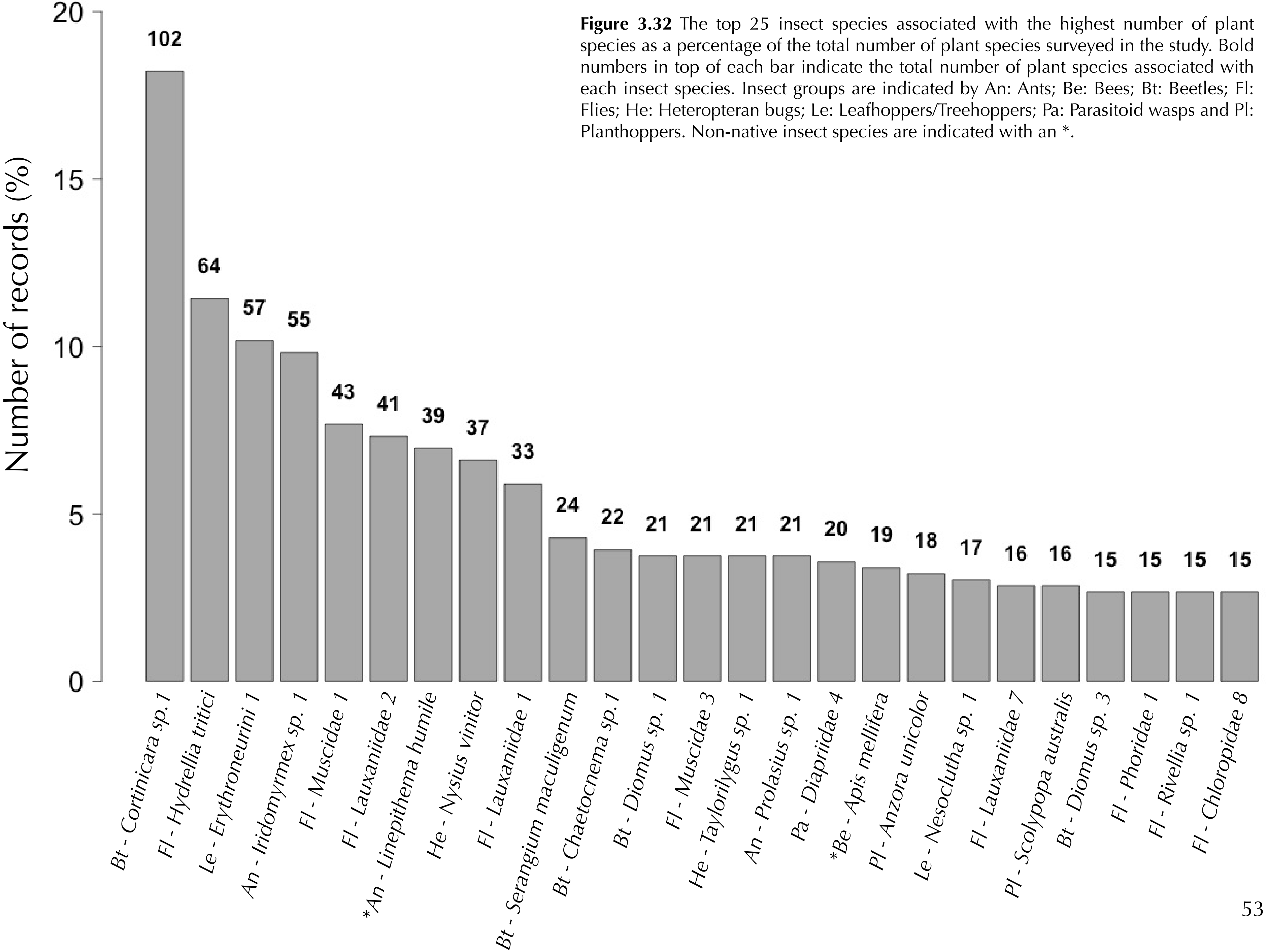

Figure 3.32 The top 25 insect species associated with the highest number of plant species as a percentage of the total number of plant species surveyed in the study. Bold numbers in top of each bar indicate the total number of plant species associated with each insect species. Insect groups are indicated by An: Ants; Be: Bees; Bt: Beetles; Fl: Flies; He: Heteropteran bugs; Le: Leafhoppers/Treehoppers; Pa: Parasitoid wasps and Pl: Planthoppers. Non-native insect species are indicated with an *.

108 plant species), the 'connectance' of the City of Melbourne's metanetwork of plant-insect ecological interactions (Figure 3.31) was approximately 4%. On average, each insect species was associated with 3.28 plant species.

Which insect species was associated with the highest number of plants?

The minute brown scavenger beetle *Cortinicara sp. 1*. Minute brown scavenger beetles (Figure 3.5) were recorded in association with as much as 102 plant species – that is almost 94% of all plant species surveyed in the study (Figure 3.32).

Which fly species was associated with the highest number of plants?

The lawn fly *Hydrellia tritici*. Lawn flies (Figure 3.6) were recorded in association with 64 plant species – that is almost 60% of all surveyed plant species (Figure 3.32).

Which leafhopper species was associated with the highest number of plants?

An erythroneurinid leafhopper [Erythroneurini 1]. This species of erythroneurinid leafhopper (Figure 3.8) was recorded in association with 57 plant species – that is more than 50% of all surveyed plant species (Figure 3.32). This species is the most generalist herbivore recorded in the study – assuming of course that it actually feeds on every plant species that we found it on.

Which ant species was associated with the highest number of plants?

Iridomyrmex sp. 1. The ant complex I*ridomyrmex sp. 1* (Figure 3.7) was recorded in association with 55 plant species (Figure 3.32).

Which heteropteran bug species was associated with the highest number of plants?

The Rutherglen bug *Nysius vinitor*. Rutherglen bugs (Figure 3.9) were recorded in association with 37 plant species (Figure 3.32).

Which bee species was associated with the highest number of plants?

The European honey bee *Apis mellifera*. Honey bees (Figure 3.12) were recorded visiting the flowers of 16 non-native plants: glossy abelia *Abelia grandiflora*, common agapanthus *Agapanthus praecox*, boxwood *Buxus sp.*, cape chestnut *Calodentrum capense*, canna lilies *Canna* *generalis* and *Canna indica*, rockrose *Cistus sp.*, pride of Madeira E*chium candicans*, lavander *Lavandula sp.*, white clover *Trifolium repens* (part of the 'lawn complex'), pennyroyal *Mentha pulegium*, spurflower *Plectranthus sp.*, rosemary *Rosmarinus officinalis*, bush sage *Salvia leucantha*, lamb's ear *Stachys byzantina* and star jasmine *Trachelospermum jasminoides*. Interestingly, we also documented the European honey bee visiting the flowers of three native plant species: spotted gum *Corymbia maculata*, burgan *Kunzea ericoides* and brush box *Lophostemon confertus*.

With how many plant species were native bee species associated?

17 Amongst these, eight are native insect-pollinated shrubs or trees: gold-dust wattle *Acacia acinacea*, varnish wattle *Acacia verniciflua*, fragant saltbush *Chenopodium parabolicum*, rock correa *Correa glabra*, common correa *Correa reflexa*, spotted gum *Corymbia maculata* (Figure 3.30), hop goodenia *Goodenia ovata* (Figure 4.1); four are native graminoid or grass species which provide non-floral resources: spiny-headed mat-rush *Lomandra longifolia*, tussock-grass *Poa labillardierei* (Figure 3.29), wallaby grass *Rytidosperma sp.* and kangaroo grass *Themeda triandra*; and six were non-native plant species (*Asparagus aethiopicus*, *Calodentrum capense*, *Dietes sp.*, 'Lawn complex', *Schinus molle* and *Strelitzia reginae*).

Which planthopper species was associated with the highest number of plants?

The grey planthopper *Anzora unicolor*. Grey planthoppers (Figure 3.10) were recorded in association with 18 plant species (Figure 3.32).

Were jumping plant louse species generalists or specialists?

Specialists Most jumping plant louse species were recorded in association with less than three plant species. For example, all five records of *Acizzia jucunda* were on black wattle *Acacia mearnsii*, and all ten records of species in genus *Mycopsylla* (*Mycopsylla sp. 1* (fici group) and *Mycopsylla sp. nov.* (tuberculata group) were on Moreton Bay fig *Ficus macrophylla*. Likewise, all six records of *Glycaspis sp. 1* (brimblecombei group) were on Myrtaceae species (river red gum *Eucalyptus camaldulensis* and spotted gum *Corymbia maculata*).

Table 3.3 Number of insect species by feeding strategy recorded in each insect group. A: Adult stage; IS: Immature stage.

		Herbivory		Fungivory		Predation		Parasitoidism		Scavenging	
		A	IS	A	IS	A	IS	A	IS	A	IS
Beetles	Coleoptera	79	64	20	20	38	35	0	0	29	36
Parasitoid wasps	Parasitica	15	1	0	0	0	0	0	123	0	0
Flies	Brachycera	7	13	0	0	17	20	0	10	58	57
Heteropteran bugs	Heteroptera	56	56	0	0	5	5	0	0	0	0
Leafhoppers/Treehoppers	Membracoidea	40	40	0	0	0	0	0	0	0	0
Jumping plant lice	Psylloidea	31	31	0	0	0	0	0	0	0	0
Stinging wasps	Aculeata	13	0	0	0	1	0	0	22	1	0
Ants	Formicidae	8	0	0	0	17	0	0	0	17	0
Bees	Apoidea	16	0	0	0	2	2	0	0	0	0
Planthoppers	Fulgoroidea	11	11	0	0	0	0	0	0	0	0
Sawflies	Symphyta	0	2	0	0	0	0	0	0	0	0
Cicadas	Cicadoidea	1	0	0	0	0	0	0	0	0	0
		277	**219**	**20**	**20**	**80**	**62**	**0**	**155**	**105**	**93**

Table 3.4 Number of insect species by herbivorous guild recorded in each insect group. A: Adult stage; IS: Immature stage.

		Exudativory (honeydew)		Folivory (leaves)		Graminivory (grass)		Nectarivory (nectar)		Palinivory (pollen)		Granivory (seeds)		Xylophagy (wood)	
		A	IS	A	IS	A	IS	A	IS	A	IS	A	IS	A	IS
Beetles	Coleoptera	0	0	58	56	0	0	3	0	45	31	1	1	0	3
Parasitoid wasps	Parasitica	0	0	0	0	0	0	14	0	15	1	0	0	0	0
Flies	Brachycera	0	0	4	13	0	0	3	0	0	0	0	0	0	0
Heteropteran bugs	Heteroptera	0	0	42	42	5	5	0	0	3	3	9	9	0	0
Leafhoppers/Treehoppers	Membracoidea	0	0	40	40	0	0	0	0	0	0	0	0	0	0
Jumping plant lice	Psylloidea	0	0	31	31	0	0	0	0	0	0	0	0	0	0
Stinging wasps	Aculeata	1	0	0	0	0	0	11	0	1	0	0	0	0	0
Ants	Formicidae	4	0	0	0	0	0	3	0	0	0	3	0	0	0
Bees	Apoidea	0	0	0	0	0	0	16	0	16	0	0	0	0	0
Planthoppers	Fulgoroidea	0	0	11	11	0	0	0	0	0	0	0	0	0	0
Sawflies	Symphyta	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Cicadas	Cicadoidea	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		5	**0**	**187**	**196**	**5**	**5**	**49**	**0**	**80**	**35**	**13**	**10**	**0**	**3**

Table 3.5 Number of insect species by regulating ecosystem service recorded in each insect group.

		Pollination	*Biomass transfer*	*Pest control*	*Soil fertility*	*Seed dispersal*
Beetles	Coleoptera	17	87	38	38	0
Parasitoid wasps	Parasitica	60	15	123	0	0
Flies	Brachycera	35	16	30	58	0
Heteropteran bugs	Heteroptera	3	56	5	0	0
Leafhoppers/Treehoppers	Membracoidea	0	40	0	0	0
Jumping plant lice	Psylloidea	0	31	0	0	0
Stinging wasps	Aculeata	15	13	23	1	0
Ants	Formicidae	2	8	17	17	3
Bees	Apoidea	16	16	2	0	0
Planthoppers	Fulgoroidea	0	11	0	0	0
Sawflies	Symphyta	0	2	0	0	0
Cicadas	Cicadoidea	0	1	0	0	0
		148	**296**	**238**	**114**	**3**

How many adult insect species were herbivores?

277 Approximately half of all adult insect species recorded in the study were herbivores, and about 18% and 14% were scavengers and predators, respectively (Table 3.3). Approximately 40% of the insect species' immature stages were herbivores, and about 27% and 17% were parasitoids and scavengers, respectively (Table 3.3.).

What parts of the plants are the herbivorous insects specialised to eat?

As much as 68% of all adult herbivorous insect species recorded in the study were folivores (Table 3.4), a herbivorous guild in which species specialise to eat leaves. This percentage was even higher for immature stages (90%). Other herbivorous guilds with numerous species were palinivores and nectarivores, with 80 (29%) and 49 (18%) adult species, respectively (Table 3.4).

What regulating ecosystem services could the recorded insect species potentially provide?

Biotic pollination, biomass transfer from plants and fungi to higher trophic levels, control of insect pests, improved soil fertility and seed dispersal (Table 3.5).

How many species were pollinators?

We don't know! What we do know is that as much as 25% of all recorded insect species are known to visit flowers to collect nectar and/or pollen – that is almost 150 species of beetles, parasitoid wasps, flies, heteropteran bugs, stinging wasps, ants and, of course, bees (Table 3.5). In many instances however flower visitation does not translate directly into pollination.

How many species transfer biomass from plants and fungi into higher trophic levels?

296 Over 50% of all recorded insect species were herbivores and/or fungivores, and therefore capable of transferring organic material from plants and fungi into higher trophic levels (Table 3.5). By consuming plants and fungi, herbivorous and fungivorous insects are in essence becoming a nutritious food source not only for insect predators and parasitoids but also for spiders, centipedes, frogs, lizards, birds, bats and many other animal groups.

How many species are providing pest control?

238 Over 40% of all recorded insect species were predators or parasitoids, and therefore

capable of regulating the populations of potential insect pests (Table 3.5).

How many species are improving soil fertility?

114 As much as 20% of all recorded species were scavengers and/or detritivores, and therefore capable of recycling nutrients from dead or decomposing organic material back into the soil (Table 3.5).

How many species are providing seed dispersal?

3 (6) These were *Rhytidoponera metallica*, *Rhytidoponera victoriae* and *Iridomyrmex sp. 1*, which in fact is a complex of species that includes *Iridomyrmex septentrionalis*, *Iridomyrmex suchieri*, *Iridomyrmex sp.* (splendens group) and *Iridomyrmex sp.* (bicknelli group). Foraging workers from all six species are known to carry elaiosome-bearing seeds back to their colonies to feed their larvae, effectively turning them into seed dispersers.

What provisioning ecosystem services are provided by the studied insect groups?

The insects recorded in the study may supply at least two types of food: honey and lerps. We documented only one species of honey-producing bee, namely the non-native European honey bee *Apis mellifera* (Figure 3.12). Lerps are crystallised protective structures made out of the sugar-rich liquid honeydew exudated by the immature stages of jumping plant lice (Cover illustration). Lerps are one of the main types of sweet foods gathered and consumed by Aboriginal Australians (Turner 1984).

Are there any ecosystem disservices provided by the studied insect groups?

Yes A few of the insect species recorded in the study may potentially cause one or more of the following ecosystem disservices: human discomfort, for example a skin rash produced by a fly's bite; allergic reactions, which may follow after the injection of venom from a wasp's sting; or plant damage, as may be caused for example to the English elm leaf by the leaf elm beetle *Xanthogaleruca luteola*.

4 Management and practice recommendations

Which management action could be prioritised with the objective to increase insect biodiversity?

Increase the amount mid-storey habitat Over 60% of the surveyed insect species were recorded in association with mid-storey plots and over 20% of all insect species occurred exclusively in this habitat type. Yet, mid-storey habitat is not a predominant feature of most of our city's urban green spaces. In fact, mid-storey habitat is currently absent from up to one third of the green space sites we surveyed. Undoubtedly, these green spaces (University Square, Pleasance Gardens, Murchison Square, Canning/Neill Street Reserve and Garrard Street Reserve), as well as many other similarly sized and structured green spaces across the municipality, could benefit from the addition of mid-storey habitat.

Which other habitat type could be promoted to increase insect biodiversity?

Grassland Although over 38% of the surveyed insect species were recorded in association with grassland plots and over 10% of all insect species occurred exclusively in this habitat type, grassland-type vegetation is currently absent from as much as 70% of the studied green spaces. Increasing the extent of grassland habitat in green spaces where this habitat type is already present (e.g. Royal Park, Westgate Park and Princes Park) and adding new grassland-type vegetation to green spaces where this habitat type is absent could potentially increase insect biodiversity in our city.

Which plant species could be prioritised with the objective of increasing insect biodiversity in the mid-storey habitat?

The following four native shrubs had the highest number of associated insect species: fragrant saltbush *Chenopodium parabolicum*, sweet bursaria *Bursaria spinosa*, gold-dust wattle *Acacia acinacea* and hop goodenia *Goodenia ovata* (Figure 4.1). We would therefore recommend them as the best candidate plant species for future plantings in existing and new mid-storey habitat. Other good options include the native graminoid spiny-headed mat-rush *Lomandra longifolia*, and the native shrubs weeping bottlebrush *Melaleuca viminalis* and ruby saltbush *Enchylaena tomentosa*.

Which plant species could be prioritised with the objective of increasing insect biodiversity in the grassland habitat?

The tussock-grass *Poa labillardierei* (Figure 3.29) was the grass species with the highest associated insect diversity in the study. In fact, as much as 18% of all recorded insect species occurred on this one plant species. We would therefore recommend this native grass species as the best option to increase insect biodiversity in existing and planned grassland habitat within the city's green spaces. Plantings of tussock-grass could be complemented with the native wallaby (*Rytidosperma sp.*) and kangaroo (*Themeda triandra*) grasses.

Are your management and practice recommendations regarding mid-storey and grassland habitats transferable to other types of green space in the City of Melbourne different to the public parks, gardens, squares and reserves investigated in this study?

Yes Our recommendations should apply equally to established green spaces, as well as to other less traditional permanent and temporary green spaces such as pop-up parks (e.g. Linda Tegg's 'Grasslands' installation; Figure 4.2; see Mata et al. in preparation for more details), median strips, nature strips, ornamental beds, perennial meadows, greenroofs and greenwalls.

Can the native tree species that are part of our city's urban forest also contribute to increase insect biodiversity?

Yes The following Australian native trees were all associated with large number of insect species (25 or more): spotted gum *Corymbia maculata* (Figure 3.30), black wattle *Acacia mearnsii*, ironbark *Eucalyptus sideroxylon*, Moreton Bay *Ficus*

Figure 4.1 The hop goodenia *Goodenia ovata*.

macrophylla, brush box *Lophostemon confertus*, drooping sheoak *Allocasuarina verticillata*, river red gum *Eucalyptus camaldulensis* and bracelet honey myrtle *Melaleuca armillaris*. We would therefore recommend strengthening their extent in the city's urban forest.

Do you have specific management recommendations regarding non-native tree species?

Australian native tree species had up to 60% more insect species than non-native ones. Yet, the highest insect diversity (57 species) was recorded on both the native spotted gum *Corymbia maculata* and the non-native pepper tree *Schinus molle*. We would therefore recommend this latter non-native species as an option to complement native tree species in strategies aimed at increasing insect biodiversity in our city's green spaces.

Do you have specific management recommendations for lawns?

Lawn was the habitat type with the smallest number of associated insect species. In fact, only 19% of all insect species were found in this habitat type and only 15 species were unique to the lawn habitat. With the objective of increasing insect biodiversity in mind, we would therefore recommend that economic investment in maintaining or extending lawns should be deprioritised and resources shifted to adding and extending mid-storey and grassland habitat throughout the municipality. When lawns are allowed to grow, however, forb species within them (e.g. white clover *Trifolium repens*) may come into flower, and thus provide floral resources for the European honey bee *Apis mellifera* (as documented in this study; Figure 4.3) and potentially also for other native and non-native flower visiting species. We would therefore recommend that lawns should be mowed with a frequency that allows the flowering plant species living within them to complete their life cycles.

Do any specific shrubs or trees deserve special management considerations?

Yes All grasses, shrubs and trees in which we documented new insect species to science should be protected from being disturbed at all cost - particularly they should not be sprayed with insecticides. These include ironbark *Eucalyptus sideroxylon* stands in Princess Park; brush box *Lophostemon confertus* and bracelet honey myrtle *Melaleuca armillaris* stands in Fitzroy-Treasury Gardens, Princes Park and Royal Park; Moreton Bay fig *Ficus macrophylla* stands in Carlton Gardens South, Fitzroy-Treasury Gardens, Lincoln

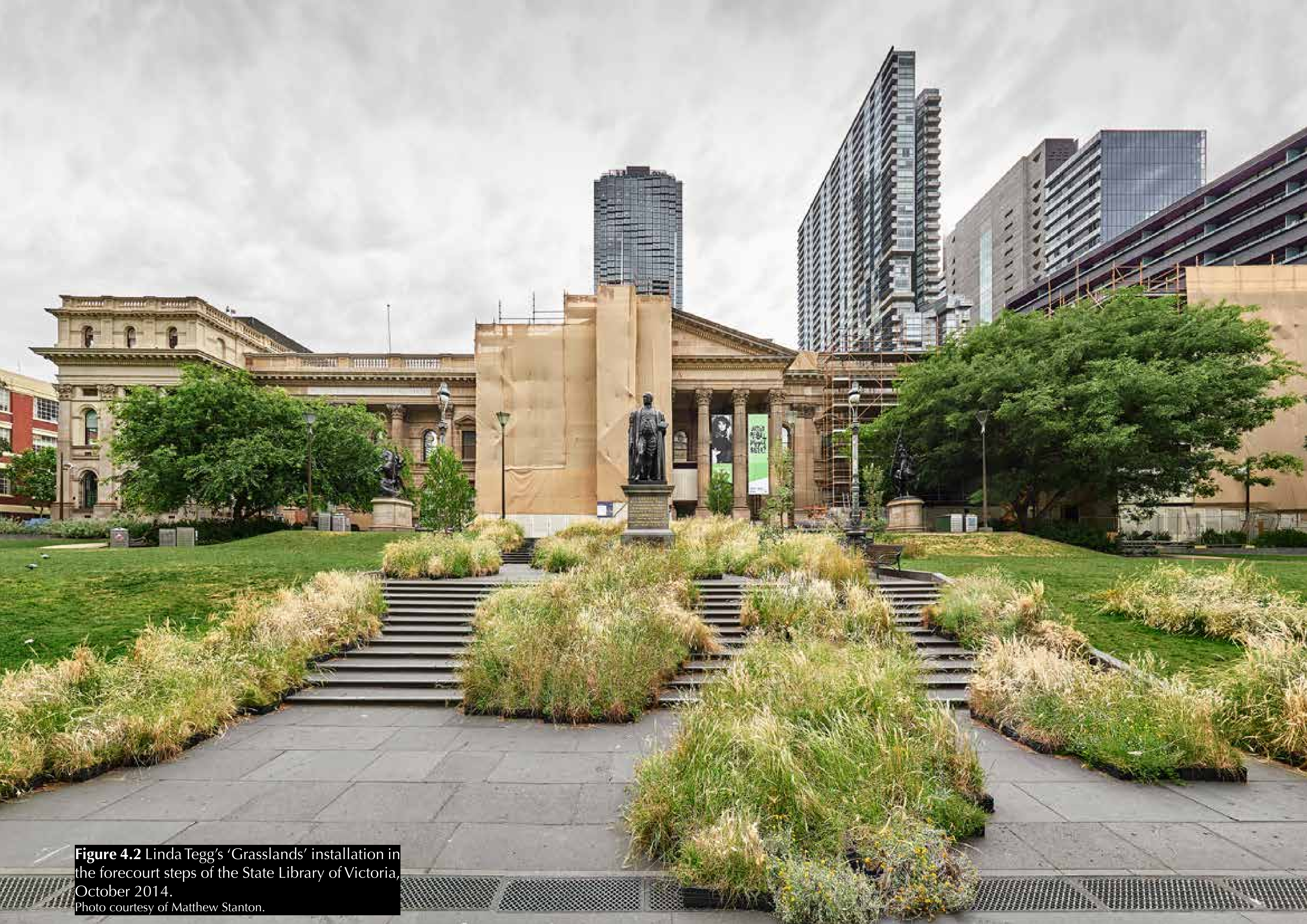

Figure 4.2 Linda Tegg's 'Grasslands' installation in the forecourt steps of the State Library of Victoria, October 2014.
Photo courtesy of Matthew Stanton.

Square and Princess Park; and tussock-grass *Poa labillardierei*, fragrant saltbush *Chenopodium parabolicum* and drooping sheoak *Allocasuarina verticillata* stands in Royal Park. Tussock-grass stands in Princes Park would also deserve special protection, as they are currently the only known location of the very rare chinch bug *Heinsius sp. 1*.

What native species would you plant to attract and provide habitat for native bee pollinators?

For their floral resources: Gold-dust wattle *Acacia acinacea*, varnish wattle *Acacia verniciflua*, fragant saltbush *Chenopodium parabolicum*, rock correa *Correa glabra*, common correa *Correa reflexa*, spotted gum *Corymbia maculata* (Figure 3.30), hop goodenia *Goodenia ovata* (Figure 4.1). And for their non-floral resources (e.g. hollows, perching sites): spiny-head rush-mat *Lomandra longifolia*, tussock-grass *Poa labillardierei* (Figure 3.29), wallaby grass *Rytidosperma sp*. and kangaroo grass *Themeda triandra*.

What research could benefit from the implementation of an insect monitoring program in the City of Melbourne?

Monitoring the occurrence of key insect herbivores, predators, parasitoids, pollinators and seed dispersers, and their associations with plants, in urban green spaces across the City of Melbourne is critical for understanding the network of interactions sustaining ecological processes, and thus ecosystem services. Ideally, and perhaps fundamental for its success, this monitoring program would include protocols to recruit and train citizen scientists. By doing so, the City of Melbourne could further strengthen the research component of its citizen science program, whilst generating essential evidence to guide future green space and biodiversity management strategies.

Is there a need to monitor any potentially problematic species that are non-native to Australia?

Yes We have found a few non-native insect species that may potentially disrupt key ecological processes occurring within the City of Melbourne's urban ecosystems. A perfect example is the non-native Argentine ant *Linepithema humile* (Figure 3.23), which was first recorded in the City of Melbourne in 1962. Evidence suggests that this aggressive invasive species is capable of displacing native ant species, and therefore interfering with ant-mediated seed dispersal. We would therefore suggest that a monitoring program to follow the

Figure 4.3 The European honey bee *Apis mellifera* visiting a flower of the white clover *Trifolium repens* in Murchison Square.

Figure 4.4 The common imperial blue *Jalmenus evagoras*.
Photo by David Cook.

Figure 4.5 The common brown butterfly *Heteronympha merope*.
Photo by John Tann.

ant's populations and meta-community structure within the City of Melbourne and adjacent municipalities would be key component of any monitoring strategy.

Would similar studies like The Little Things that Run the City add to our knowledge of insect ecology, biodiversity and conservation in the City of Melbourne?

Yes Our study was aimed at identifying the occurrence, distribution and ecological interactions of key insect groups within the City of Melbourne in a wide range of green spaces and habitat types. Yet, due to the complex nature of insect biodiversity, it is unlikely that a single study could capture this diversity completely. For example, an insect survey specifically targeted at butterflies and moth species could greatly improve our understanding of Lepidoptera biodiversity, particularly of the degree by which the immature stages (i.e. caterpillars and pupae) associate with native and non-native host plants, and the role of adult butterflies in pollination. This understanding is important given the recent interest in targeting key charismatic and culturally significant butterfly species such as the common imperial blue *Jalmenus evagoras* (Figure 4.4) and the Common brown butterfly *Heteronympha merope* (Figure 4.5) for potential rewilding programs (Mata et al. 2016).

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